H. O. No. 216

AIRCRAFT NAVIGATION MANUAL

U. S. NAVY

FIRST EDITION

Prepared at Pensacola Ground School and published by the Hydrographic Office under the authority of the Secretary of the Navy

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PREFACE

For many years the Hydrographic Office has been considered the principal source of navigation manuals and tables for surface vessels. Consequently, officers of the Navy and the Merchant Marine have always looked to the Hydrographic Office for the most up-to-date methods. When the special needs of the air navigator became evident the Hydrographic Office originated and published several short methods for general use in celestial navigation.

The first Manual of Air Navigation produced in the Hydrographic Office, however, included so much material having particular reference to naval aviation that its issue was restricted to the Naval Service. In view of the enormous program of aviation training under way, it was considered that the manual should be revised in such form that it could be made available to the public. In preparing this edition, the course in navigation at the Naval Air Station, Pensacola, Fla., has been used as a basis, and the material prepared by officer instructors at that station in cooperation with the Hydrographic Office. Every effort has been made to eliminate extraneous material and to present the necessary theory in the simplest possible terms. Where practicable an adequate number of problems and answers for self-instruction has been presented. This publication therefore should be of value both to the student aviator and to the service pilot.

The material for the manual was prepared by Lt. W. L. Kabler, United States Navy; Lt. F. A. Davisson, United States Navy; Lt. (jg) M. M. Martin, United States Navy; Lt. (jg) J. A. Lamade, United States Navy; Lt. (jg) E. S. Quilter, United States Naval Reserve; and Lt. (jg) H. E. Cook, United States Naval Reserve, while on duty as ground school instructors at the Naval Air Station, Pensacola, Fla. It was arranged and edited by the Hydrographic Office.

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CHAPTER I

NAVIGATION DEFINITIONS, CHARTS, AND PUBLICATIONS

NAVIGATION DEFINITIONS

The following terms and definitions relating to navigation are in common use and should be thoroughly understood:

The shape of the earth is approximately that of an oblate spheroid, that is, an ellipsoid of revolution whose shortest axis is the axis of revolution. Its longer or equatorial diameter is about 6,884 nautical miles, and its shortest or polar diameter about 6,860.5 miles. For the purpose of navigation this small departure from an exact spherical form is usually disregarded and the earth assumed to be a true sphere.

Air navigation is the art of determining the observer's geographical position, and maintaining desired motion of an aircraft relative to the earth's surface by means of pilotage, dead reckoning, celestial observations, or radio aids.

A *sphere* is a body bounded by a surface, all points of which are equally distant from a point within called the center (fig. 1).

A *great circle* is a circle on the surface of the earth, the plane of which passes through the center of the earth.

A *small circle* is any circle other than a great circle on the surface of the earth.

The *axis* of the earth is the diameter about which it rotates. The north end of the axis is the north pole and the south end is the south pole.

The *equator* is that great circle of the earth which lies midway between the poles. The plane of the equator is perpendicular to the axis at its midpoint and all points on the equator are 90° from the poles.

Parallels, or *parallels of latitude*, are small circles of the earth's surface whose planes are parallel to the plane of the equator.

Meridians are great circles of the earth which pass through the poles. The plane of every meridian contains the earth's axis, and the meridian is bisected by the axis. The upper branch of the meridian is that half which passes through the position of the observer, and the lower branch is the half that lies on the other side of the earth's axis. The name "meridian" is commonly used to denote only the upper branch of the meridian.

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The *prime meridian* is the meridian used as a line of origin for the measurement of longitude. The meridian whose plane passes through the observatory at Greenwich, England, is used as the prime meridian by most countries, including the United States.

The *latitude* (symbol L) of any point on the surface of the earth is its angular distance north or south of the equator. Latitude is measured from 0° to 90° north or south of the equator to the poles

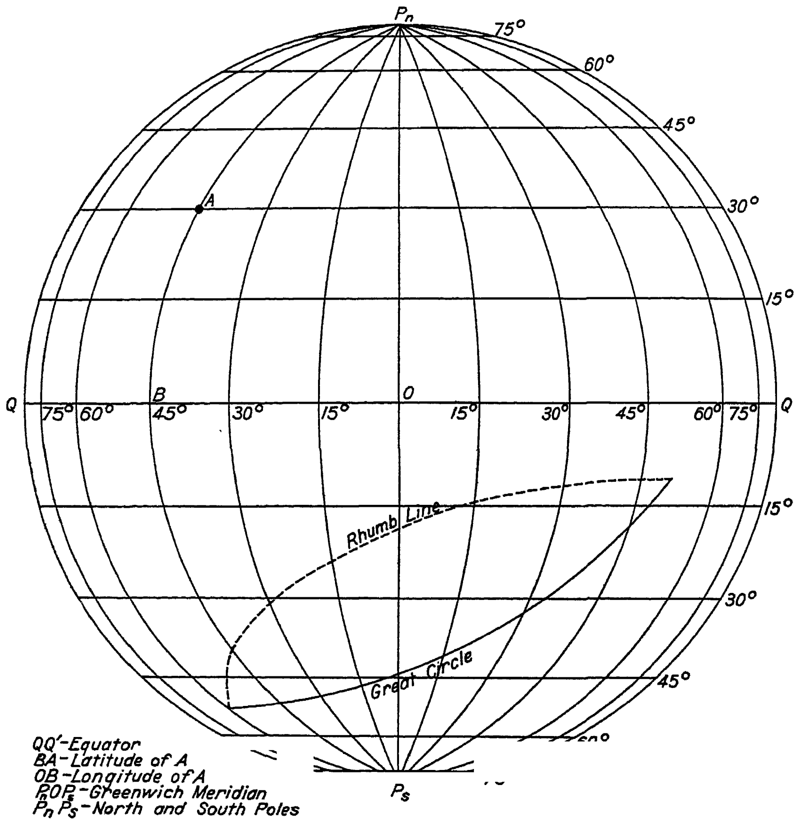

FIGURE 1.—The earth.

along a meridian and is expressed in degrees, minutes, and seconds of arc.

The *difference of latitude* (symbol DL) between any two places is the angular measure of the arc of a meridian intercepted between their parallels of latitude. Between two places on the same side of the equator their latitudes are subtracted to obtain DL, between two places on opposites sides of the equator their latitudes are added to obtain DL.

The *longitude* (symbol Lo) of a place is the arc of the equator included between the prime meridian (Greenwich) and the meridian

of the place. Longitude is measured from 0° to 180° east or west of the prime meridian and is expressed in degrees, minutes, and seconds of arc. It may also be expressed in units of time as hours, minutes, and seconds.

The *difference of longitude* (symbol *DLo*) between two places is the length of the smaller arc of the equator intercepted between the meridians of the places. If both places are in east longitude, or both in west longitude, it is equal to the result obtained by subtracting the smaller from the larger. If the places are in longitudes of different names, i. e., east and west, it is equal to the sum of their longitudes, or, if the sum exceeds 180°, it is equal to 360° minus the sum.

The *direction* of a line which passes through a point on the earth is the inclination of the line to the meridian of the point. It is measured from 0° at north around to the right (clockwise) through 360°. Since the meridians are only imaginary circles marked on maps and charts but not actually on the surface of the earth, the direction of the observer's meridian must be determined before the direction of a given line can be obtained.

The *true bearing* of a place on the earth's surface from the place of an observer is the angle between the great circle joining the two places and the meridian of the observer.

The *shortest distance* between two places on the earth's surface is the shorter arc of the great circle passing through the two places. Thus the shortest distance between two points on the equator is the distance measured along the equator. Similarly, the shortest distance between two points on the same meridian is the distance measured along that meridian. In the first case the shortest course between the two places will make the same angle (90°) with every meridian crossed. In the second case the course will maintain a constant angle (0°) with the meridian. For any other cases the great circle course will cut each meridian at a different angle.

A *rhumb line* is a line on the earth's surface which intercepts all meridians at the same angle. Any two places may be connected by such a line. The equator, meridians, and parallels are special types of rhumb lines and are usually considered separately. All other rhumb lines are loxodromic curves or spirals which approach but never reach the poles.

The *statute mile* is 5,280 feet. This is an arbitrary unit of length which has been adopted as standard in the United States.

The *nautical mile* is 6,080.27 feet. This length was chosen because it is practically the length of 1′ of arc of a meridian or 1′ of arc of the equator. The nautical mile is approximately one-seventh longer than the statute mile and conversely the statute mile is approximately one-eighth shorter than the nautical mile.

A *knot* (symbol *kt* or *kts*) is the unit of speed used in navigation, and is equal to 1 nautical mile per hour.

A *fathom* is 6 feet. Depths of water on charts are generally expressed in fathoms but sometimes are shown in feet.

Charts and Projections

A representation of the earth's surface, or a portion of it, on a plane surface is called a *chart* or *map*. A chart or map is one of the most important items of navigation equipment. If the destination is not in sight the navigator determines from a chart or map the direction and distance to travel in order to reach the desired destination. By fixing his position on the chart during the flight, the navigator can check the direction and distance actually flown and immediately detect any changes necessary to reach his destination. If the chart is constructed for aerial use, the location of airports, radio aids to navigation, type of terrain, and many other features of use to the pilot will be shown.

Because the earth is a sphere, sections of it cannot be transferred to a plane surface without some distortion. To systemize this distortion, various types of projections have been devised. The four most commonly used for navigational purposes are:

1. The Mercator projection.
2. The Lambert conformal projection.
3. The polyconic projection.
4. The gnomonic projection.

MERCATOR PROJECTION

This type of chart is constructed by projecting the surface of the sphere on a cylinder tangent to the earth at the equator. Meridians of longitude appear as vertical straight lines, parallel and equidistant. Parallels of latitude are represented by parallel straight lines at right angles to the longitude lines. It can be readily seen from figure 2 that the length of the meridians between the parallels of latitude increases as the projection departs from the equator and that the distortion would become impossibly great if the whole projection were considered to originate at the center of the earth. In order to reduce this distortion the origin is moved up the axis of the earth at an increasing rate so determined that the increase in the distortion of the parallels of latitude is directly proportional to the increase in the parallels of longitude. The distortion of the latitude and longitude lines involves the distortion of the physical features on the earth's surface. This is especially true in extreme latitudes where Greenland appears larger than South America, although it is in reality about one-ninth its size.

The features of the Mercator projection that make it particularly adaptable to navigational uses are that all parallels of latitude and meridians are straight lines perpendicular to each other. Locations can be conveniently plotted by means of a straightedge and any course line connecting two points will be a straight line that makes equal angles with all parallels of latitudes, or meridians. Courses will then be rhumb lines indicating the true direction of any point from any other point. These features outweigh the disadvantage of

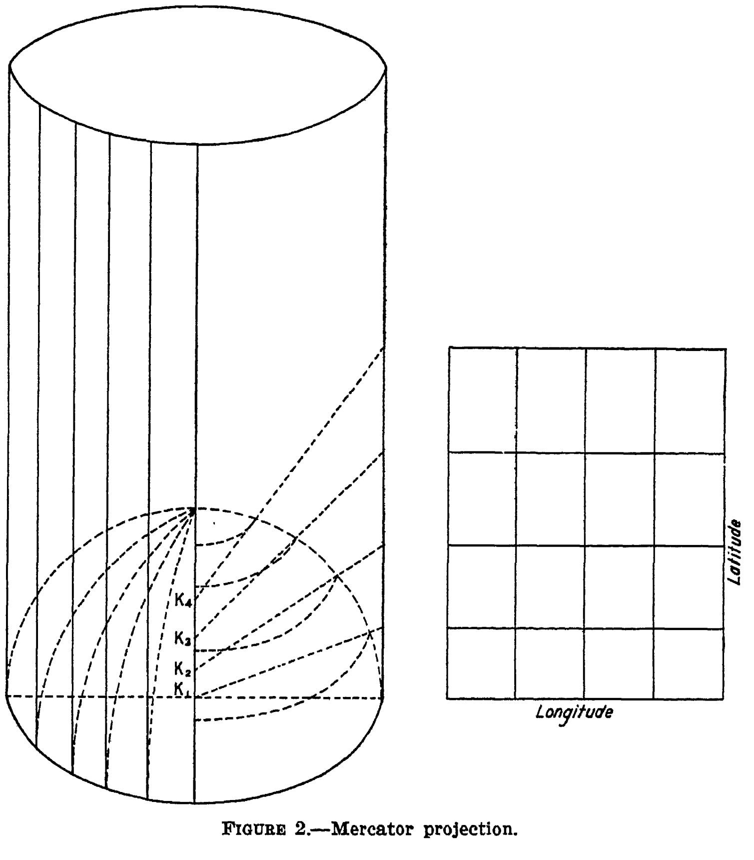

FIGURE 2.—Mercator projection.

distortion as far as navigation is concerned and this type of chart has come into general use for that purpose. One other disadvantage of the Mercator projection is its inability to portray great circles as straight lines. Great circles being the shortest distance between two points, it would be desirable to plot them as straight lines. On a Mercator chart they would appear as curves with all the disadvantages of plotting. In order to utilize great circles on a Mercator chart it is necessary to break up this curve into a series of chords. The accepted method of doing this is to utilize a gnomonic

chart where the great circles appear as straight lines and then transfer coordinates of sections of it to the Mercator chart where the circle would appear as a series of chords approximating the curve. In order to plot radio bearings a table of corrections has been published which permits the portraying of radio bearings as Mercator bearings. (See H. O. Pub. No. 205, Radio Aids to Navigation.)

Due to the distortion in the Mercator chart it is apparent that the distance scale will vary with the latitude. The longitude scale, except at the equator, is also much distorted and will not accurately indicate the true measurement of distance. Therefore, to measure

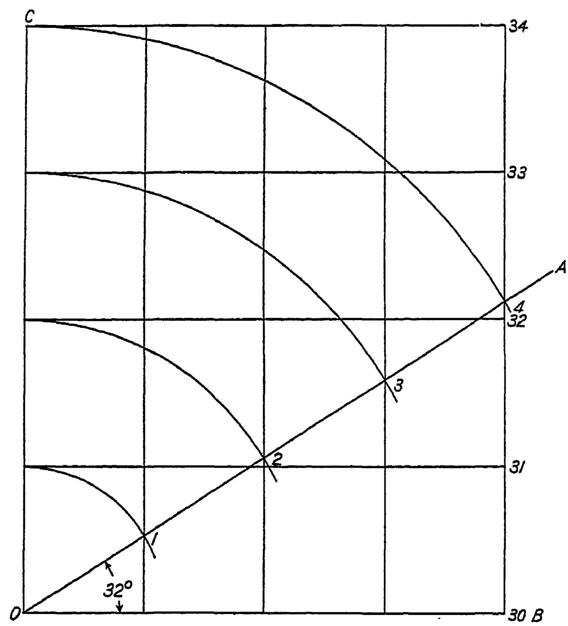

FIGURE 3.—Construction of approximate Mercator chart.

the distance on a Mercator chart the latitude scale corresponding to the middle latitude of the line must be used. In other words, a minute of arc of latitude will be equal to a nautical mile at the same latitude.

Construction of a small Mercator chart.—Very often it is necessary to construct a small Mercator chart of a locality. As an example, a small Mercator chart from latitude 30° N. to latitude 34° N. is desired. Draw the horizontal line *OB* (fig. 3). At *O* erect the perpendicular *OC*. Draw *OA* at an angle with *OB* equal to the middle latitude. On *OA* mark off the points 1, 2, 3, and 4 at equal intervals. Through these points draw the longitude lines parallel to *OC*. With *O* as a center, strike arcs on *OC* with radius equal *O*1, *O*2, *O*3, and

O4. Where the arcs intercept *OC* draw latitude lines parallel to *OB*. The latitude and longitude may then be subdivided into minutes by any method. While not an exact reproduction of a Mercator chart, since the distance between parallels of latitude will be the same, it will be sufficiently exact for all purposes if the north and south area is restricted to about 4° and the latitude of the chart is less than 60°.

Measurement of course and distance on a Mercator chart.—Compass roses oriented to true north are printed on Mercator charts for the measurement of courses. If it is desired to find the course from point *A* to point *B* (fig. 4) the two points are connected by a straight line and the direction of this line found by referring it to the com-

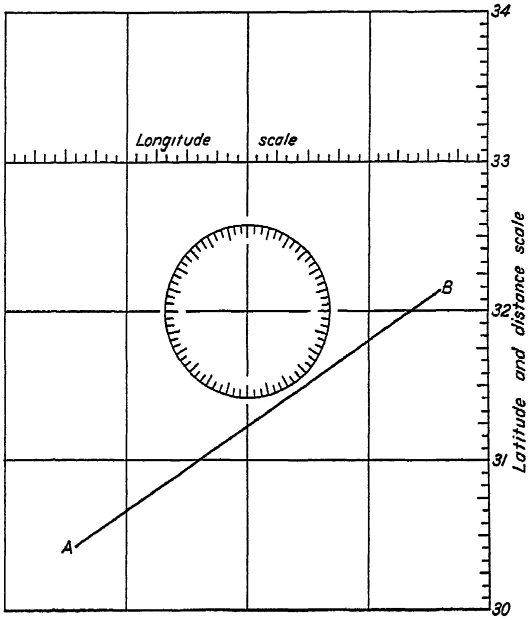

FIGURE 4.—Measurement of course on a Mercator chart.

pass rose. This may be accomplished by placing the top edge of parallel rulers along the course line and moving them parallel to the line *AB* through the center of the compass rose. The reading at the compass rose will indicate the Mercator course. Since all meridian lines point to true north the course may be also measured by measuring the angle between the course line and a meridian with a protractor and referring this angle to true north. To measure the distance *AB* take that distance on a pair of dividers, place the dividers on the latitude scale with the middle of the dividers at about the middle latitude of the line *AB*. *Never use the longitude scale in measuring distance.*

LAMBERT CONFORMAL PROJECTION

This type of projection is old but came into general use during the World War. It consists of a projection on a cone which intersects the earth's sphere at two parallels of latitude (fig. 5).

On the developed chart all meridians will appear as straight lines converging at a point beyond the limits of the chart. All parallels of latitude will be arcs of concentric circles whose center is the intersection of the meridians. Meridians and parallels intersect at right angles, and the angles formed by the intersection of any two lines will correctly indicate their angular relation.

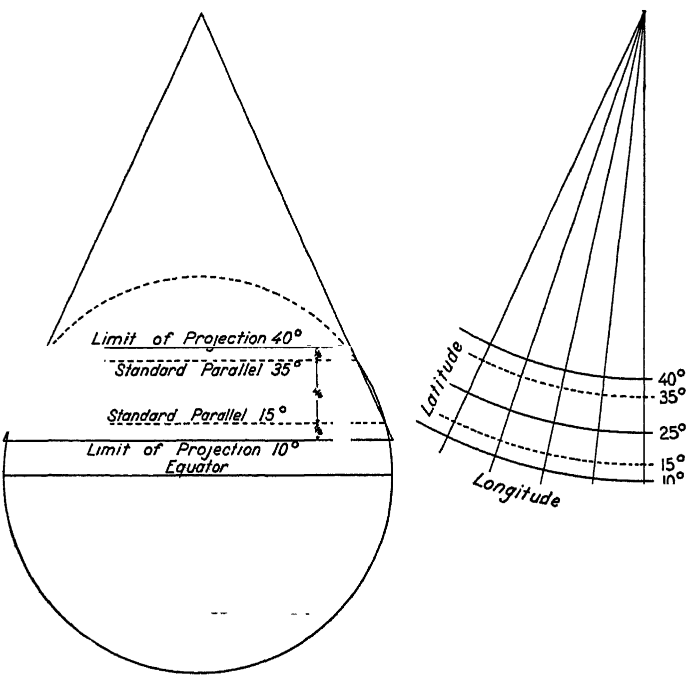

FIGURE 5.—Lambert conformal projection.

This type of chart is particularly valuable for portraying large longitudinal areas. The distortion is reduced by having two reference parallels where the projection is exact; consequently where the included latitude is kept relatively small the accuracy of the chart is greater than in most projections, especially in the higher latitudes. In general, the parallels of intersection are so chosen that one-sixth of the area to be projected is above and below these parallels.

Because of the lack of distortion, this type of chart has been adopted by many commercial cartographers. The Department of Commerce utilizes this projection for aviation sectional charts because these charts are generally of land areas and the conformation

of the physical features are more accurately portrayed. Unfortunately, courses are not rhumb lines, although errors are rather small for relatively small areas.

Measurement of course and distance on a Lambert conformal chart.—On a Lambert conformal chart a straight line joining two points will cut all meridians at a different angle and consequently a different course. To measure the course from A to B (fig. 6) measure the angle at the meridian nearest halfway between the two points. An aircraft following that course will not exactly follow the straight line AB on the chart but will slightly depart from it near the middle of the route as indicated by the dotted line. The distance scale on a Lambert chart is practically constant. The distance AB might be measured by referring that distance to a distance scale; or, if no

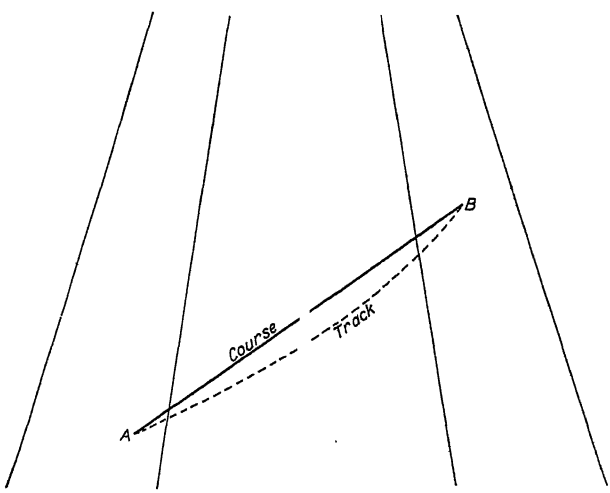

FIGURE 6.—Measurement of course on a Lambert conformal chart.

distance scale is provided, then by referring it to the latitude scale. It should be remembered that distance measured on a latitude scale is in nautical miles.

POLYCONIC PROJECTION

This projection is based upon a series of cones tangent to the sphere at selected parallels of latitude (fig. 7). A central meridian is assumed upon which the parallels of latitude are truly spaced. Each parallel is then separately developed upon a cone tangent to the earth at that parallel. On the developed chart the central meridian will appear as a straight line, but all other meridians will appear as curves, the curvature increasing with the longitudinal distance from the central meridian. The parallels of latitude will be arcs of circles, their centers lying in the extension of the central meridian. The

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distortion in latitude will be even less than that of the Lambert conformal projection, and for large north and south areas this projection has many advantages. Because of the curvature of all reference lines, it is not suited to navigational use except for pilotage.

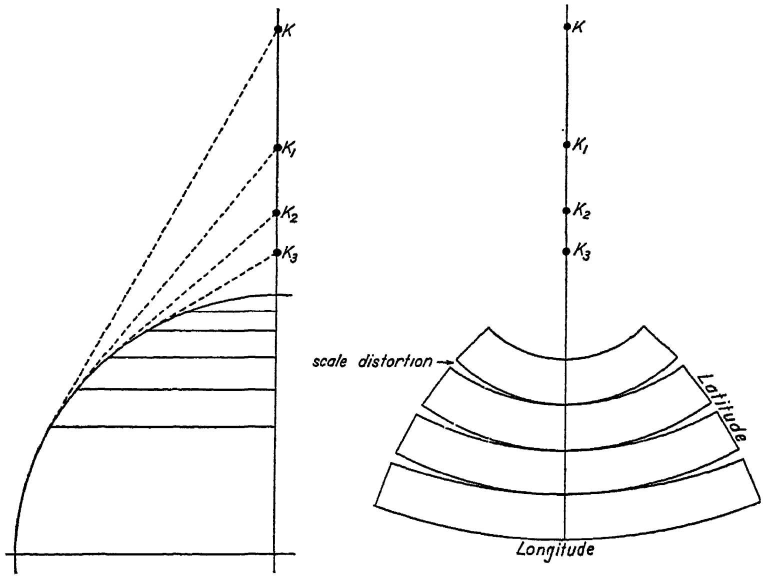

FIGURE 7.—Polyconic projection.

GNOMONIC PROJECTION

The desirability of a chart showing great circles as straight lines is apparent, and this projection was devised for that purpose. The projection is based upon a plane tangent to the sphere at a centrally located point (fig. 8).

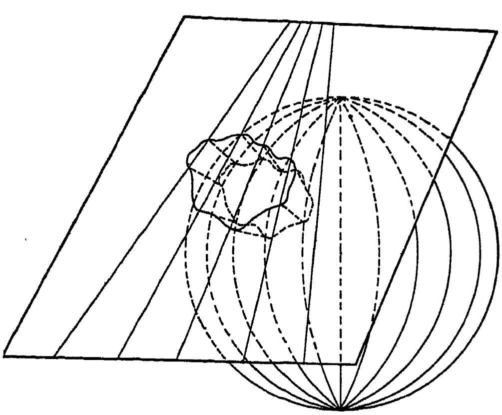

FIGURE 8.—Gnomonic projection.

The eye of the projector being at the center of the earth will cause all great circles to appear as straight lines. Parallels of latitude, except the Equator, will all be curved lines. Since the shortest distance between any two points on the earth's surface will be a portion of a great circle, this projection is extremely valuable for plotting long courses. In actual practice coordinates of sections of

these lines are transferred to Mercator charts, where they appear as a series of chords. The chords are of sufficient length to avoid too frequent course changes and yet to approximate the circle itself. The gnomonic projection is of little value except for the above feature, since the distortion is very large at relatively short distances from the point of tangency and the distance scales are extremely complicated. Charts of this nature are published for the sole purpose of laying off great circle routes and plotting radio bearings. Each chart has an explanation of the measurement of course and distance printed on it.

The chart table gives a brief summary of the advantages, disadvantages, uses, and sources of the different projections.

CHART TABLE

	Mercator	Lambert conformal	Polyconic	Gnomonic	
Features	*Meridians.*—Parallel, equidistant, straight lines. *Parallels of latitude.*—Straight lines perpendicular to meridians.	*Meridians.*—Converging straight lines. *Parallels of latitude.*—Circles concentric and equidistant.	*Meridians.*—Curved lines except central one. *Parallels of latitude.*—Circles, different radii.	*Meridians.*—Converging straight lines. *Parallels of latitude.*—Curved lines.	Features
Advantages	Line between two points indicates true course or bearing. Ease at plotting. Charts of same scale can be joined. Scale is in nautical miles.	Course lines nearly great circles. Distortion reduced. Physical features in correct proportions. One scale for entire map.	Minimum distortion. Universal scale. Good for small areas.	Great circles appear as straight lines permitting plotting of radio bearings and measurements of shortest distances between two points.	Advantages
Disadvantages	Expanding latitude and distance scale. Straight line does not portray shortest distance. Distortion especially in high latitudes. Radio bearings must be corrected for plotting.	Course lines not accurately portrayed. Plotting difficult. Plotted track and track traveled not the same.	Course lines for all but short distance incorrectly shown. Difficulty in plotting.	Great distortion, except near point at tangency. Different scales throughout map.	Disadvantages
Uses	Most surface craft navigation charts. Coastal aviation charts. Plotting sheets.	Department of Commerce sectional and regional maps. Commercial maps.	Army tactical and ordnance maps. Surveys.	Great Circle plotting. Plotting radio bearings.	Uses
Source	Hydrographic Office.	Department of Commerce. Commercial.	United States Army.	Hydrographic Office.	Source

Chart Reading

Aviation charts.—The high speed and range of aircraft makes it extremely important that there be available to the pilot a chart of the area over which the aircraft is flying. It was early realized that the type of chart suitable for surface craft navigation would not suffice for aviation purposes. Physical features which would be prominent reference points for the aviator would be unimportant to the surface navigator. All aviation charts show landmarks and other information found of value by pilots long familiar with the region. In depicting this information, use is made of many conventional symbols.

The features shown may be divided into two groups:

1. Those necessary for a clear and accurate topographical representation.

2. Aeronautical data and information of interest chiefly for air navigation.

The topographical features are divided into three parts:

Drainage, including streams, lakes, canals, swamps, and other bodies of water.—These features are shown in blue, small streams and canals by a single blue line, the larger streams and other bodies of water by blue tint within the solid blue lines outlining their extent.

Culture.—Such as towns, cities, roads, railroads, and other works of man. Cultural features are generally indicated in black. Railroads have cross-tie spacing at 5-mile intervals. An abandoned or torn-up railroad is indicated by a broken black line if still of value as a landmark. Roads are indicated by purple lines of two different sizes. The larger size indicates the more prominent roads as seen from the air.

Relief.—Including mountains, hills, valleys, and other surface features. Relief is shown by contour lines and by a series of gradient tints ranging from green at sea level to a dark brown above 9,000 feet.

Aeronautical data and information of interest chiefly to air navigation are generally shown in red. These data are subject to change, and for this reason new editions are printed frequently to show the latest information available. The date of the edition is always shown on a chart, and before using any chart always check to ensure using the latest information available.

Department of Commerce Charts

The following aeronautical charts are published by the Coast and Geodetic Survey of the Department of Commerce:

Sectional charts of the entire United States, in 87 sheets, at a scale of 1:500,000, or about 8 miles to the inch.

Regional charts, to cover the whole country, in 17 sheets, at a scale of 1:1,000,000, or about 16 miles to the inch.

Radio direction finding charts of the entire United States, in 6 sheets, at a scale of 1:2,000,000, or about 32 miles to the inch.

Aeronautical planning chart of the United States, at a scale of 1:5,000,000, or about 80 miles to the inch.

Great circle chart of the United States, at approximately the same scale as the planning chart.

Magnetic chart of the United States, showing lines of equal magnetic variation, at a scale of approximately 1:7,500,000, or about 115 miles to the inch.

Civil Aeronautics Authority Publications

The following bulletins relating to aerial navigation containing information of use to the aerial navigator are published by the Civil Aeronautics Authority.

Civil Aeronautics Journals.—Semimonthly bulletins of general information of interest to all aviation organizations.

Weekly Notices to Airmen.—This publication contains recent information covering the establishment and changes in status of landing fields, aeronautical lights and beacons, and other aids to air navigation within the United States.

Tabulation of Air-Navigation Radio Aids.—Issued monthly, listing the location, frequency, call letters, identifying signal, range bearings, of all air-navigation radio aids and the weather broadcast schedules.

Hydrographic Office Charts and Publications

The Hydrographic Office, Navy Department, issues navigational charts of the world as listed in its catalog. Many of these charts are suitable for aircraft use, especially for long flights and for ascertaining the suitability of harbors for aircraft operations. Strip and sectional charts of certain coastal areas outside the continental limits of the United States are printed on the Mercator projection for aviation use.

For navigational uses over sea areas the Hydrographic Office issues a series of plotting sheets for various latitudes from the equator up to 56°. These are on a scale of about 3 inches to 1° of latitude and, being on the Mercator projection, are particularly useful for plotting courses and for celestial navigation. Meridians are left unnumbered so that they can be used for any longitude. For aviation use an adaptation of this sheet has been printed. These are on a smaller scale, and each degree of latitude and longitude is divided into 10-minute rectangles. Compass roses are distributed in a convenient

manner so that portions of each sheet can be used separately. In addition to these sheets, a universal plotting sheet is issued which may be used in all latitudes by properly placing the meridians.

Aircraft plotting sheets.—

VP-0 Universal.

VP-1 Latitude 0°–11°. Panama.

VP-2 Latitude 9°–20°. Guantanamo.

VP-3 Latitude 18°–29°. Hawaii.

VP-4 Latitude 27°–38°. California and Chesapeake Bay.

VP-5 Latitude 36°–47°. San Francisco and Narragansett.

VP-6 Latitude 45°–56°.

Pilot charts of the upper air.—The Hydrographic Office issues a monthly chart of the upper air for the North Atlantic and North Pacific Oceans. These charts show average conditions of wind, fog, temperatures, and barometric pressures for each month for various localities. This information is particularly valuable for predicting conditions to be encountered in any locality at any time of the year. On the back are printed various items of interest to the pilot and navigator.

Naval Air Pilots.—A series of books containing information about the aviation facilities of various places including weather, description of possible landing places, and other pertinent data.

Notice to Aviators.—Monthly, the Hydrographic Office issues a pamphlet containing recent information covering the establishment and change in status of landing fields, seaplane anchorages, aeronautical lights, radio beacons, and other aids to air navigation in North and South America. It is designed to be used to correct naval air pilots and aviation charts.

Memoranda for Aviators.—These are issued as necessary to convey urgent warnings, or information of a temporary nature of interest to aviators.

Navigation books.—Navigation books and tables published by the Hydrographic Office are issued to both surface ships and aircraft. These books are listed in the Hydrographic Office catalog. Of particular interest to aviators are:

H. O. 205—Radio Aids to Navigation.

H. O. 208—Navigation Tables for Mariners and Aviators (Dreisonstok).

H. O. 211—Dead Reckoning, Altitude, and Azimuth Tables (Ageton).

H. O. 214—Tables of Computed Altitude and Azimuth.

Both the Hydrographic Office and the Department of Commerce maintain branch offices and agencies throughout the United States where their publications may be consulted or purchased.

CHAPTER II

AIRCRAFT NAVIGATION INSTRUMENTS

In the course of flight instruction the student pilot becomes familiar to a certain extent with various of the more common types of aviation instruments. Considerations of weight, expense, difficulties of installation, upkeep, and repair, necessitate keeping the number of instruments at a minimum. When in a service aircraft the pilot may feel assured that the value of every instrument on the panel has been completely demonstrated.

Intelligent use of an instrument necessitates a knowledge of its purpose, capabilities, limits of accuracy, the principles upon which the instrument is designed, and its inherent errors. This chapter is concerned with these features of the more common types of navigation instruments rather than the details of construction.

There are certain considerations applicable to the design of all aircraft instruments. They are necessarily subjected to extremely severe conditions. They must withstand shocks, vibration, tilting, accelerations, low temperatures, and reduced air pressures due to altitude. The materials used should be such that the parts of the instrument will not be damaged nor its performance affected by corrosion. The parts of the mechanism should be balanced to reduce tilting and acceleration errors. Errors due to temperature variation need to be eliminated so far as possible by temperature compensation. The size and weight of the instruments are of extreme importance. Every pound of weight added by the instruments detracts from the useful load of the aircraft. In airplanes, limited space requires that the instruments be kept as small as possible, consistent with sufficiently open scales. For a time the necessity to conserve space on the instrument panel gave way to vertical indicating instruments. However, round instruments are standard today. The aircraft instruments in common use are flat-faced, with large, distinct markings. The compass is an exception, it being circular-faced. Finally, it is obviously desirable to have the indicating elements on the instrument panel in front of the pilot, which introduces the problem of designing a transmission system for distant indicating mechanisms.

Instruments are classified as navigational instruments and powerplant instruments. The former comprise all operating and navigation units, whereas the latter include those essential for operating

the engine. The automatic pilot is an accessory in fact; but since it embodies instruments and is instrumental in character, it is regarded as a part of the navigational instrument installation. There are other instruments in the airplane, such as those required for radio, ordnance, etc., but the instrument panel in the pilot's cockpit is limited usually to navigation and power-plant instruments. This discourse will be limited to navigational instruments.

Installation.—The instruments to be installed in an airplane are dependent on the function of the airplane. Instruments are installed on one or more instrument panels, together with other operating items such as switches, valves, controls, etc. Although attempts are made to group instruments in a certain order, and with relation to each other, variations in aircraft are common. Limitations of space, the form of the space, and the location of the space available for instruments, as well as operational factors, control the arrangement of the instrument panel.

Instrument panels are installed perpendicular to the fuselage center line or perpendicular to the line of sight. They are located as a whole immediately inside the fuselage, with definite relation to the pilot. The controls of an airplane preclude the utilization of all the space below the panel for expansion of the instrument board.

The usual practice to determine the arrangement of instruments in a service airplane is to make a mock-up of the installation in the mock-up of the cockpit as a whole. The trials of the airplane are sufficiently extended to give decision as to whether or not the arrangement requires modifications. There may be several adjustments before the ideal is accomplished because interferences are numerous and complicated.

Service use, maintenance, etc.—Ordinarily, difficulties experienced with aircraft instruments are due to external influences. Corrosion, leaky cases, or water in the lines will give erratic readings. Subjecting instruments to abnormal handling or to pressures beyond their capacity may cause failures. Although every instrument has inherent errors it is not often that the error is beyond the point where the instrument can be used.

Since aircraft instruments are delicate mechanisms their repair and overhaul is a matter for shops equipped for that special work The maintenance of instruments is minor, some indicators being good for a lifetime of service without any oiling or touching-up whatsoever. In case an instrument fails or its accuracy is doubted, replacement as a unit is logical. Laboratories and instrument shops are equipped to diagnose difficulties with facility. Tests and calibrations are a part of the check-out of a shop, whereas these same features are at best difficult in the field.

Instrument flying.—Prior to proceeding with the description of the instruments it is considered advisable to set forth a few of the principles involved in instrument flying.

The term "instrument flying" is much to be preferred to the older and more common expression, "blind flying." In the first place absolute blind flying has been proved a physical impossibility. In investigating the subject the N. A. C. A. carried out careful tests with selected Army, Navy, and commercial transport pilots. It was discovered that under a hood without the use of instruments, that is completely blind, none of them could retain control of the aircraft.

An airplane pilot has three "senses" which are affected by the position of his aircraft in relation to the horizontal: (1) His eye, which uses the natural horizon as a reference; (2) his inner ear, which is really a minute form of liquid level; (3) his "deep muscle sense," or the feel of his own weight. If poor visibility prevents the use of the eyes to observe the natural horizon, it has been found that the deep muscle sense and the inner ear cannot cope with the problem of defining the horizontal. This is largely due to the fact that these senses are taught to indicate the pull of gravity and cannot distinguish between that pull and the pull of other forces which act on them in flight, such as accelerations caused by change of speed or centrifugal force.

It is absolutely imperative therefore that in instrument flying the pilot rely on the instruments rather than his senses. Instrument readings are definitely more reliable than human estimates.

To have an idea of the indications of the instruments, with various actions of the airplane, reading of the instruments in daylight with specific action of the airplane will facilitate understanding. Producing an instrument indication by an action is the logical sequence. Translation of instrument readings to a picturization of the airplane action may be confusing unless it is limited to the simple actions.

Altitude Measuring Instruments

The purpose of the altitude instrument in an aircraft is to show the altitude of that craft above some point on the earth's surface. Except for local flights the usual reference point is sea level for the reason that charted information regarding the surface of the earth refers to the altitude or elevation above sea level.

Although many types of devices can be devised for measuring altitude, an adaptation of the barometer affords a simple direct reading instrument that fulfills the requirements more thoroughly than any other. In airships when extreme accuracy is necessary a more bulky instrument may be used. This discussion will be con-

fined to the barometric method of measuring altitude because of its universal use.

The pressure of the atmosphere varies with altitude and when the two are plotted the result is a logarithmic curve. The table on the following page gives the altitude-pressure-temperature relationship for standard conditions. The altimeter is calibrated in accordance with this table. If the atmosphere were in static equilibrium the use of the barometric type altimeter would be extremely simple. However, since atmospheric conditions are constantly changing, its use becomes more complex, and it is subject to many errors, some of which may be offset by making suitable corrections. In the first place the instrument does not measure altitude, it measures pressure but is calibrated in altitude units in accordance with the altitude-pressure relationship of the standard atmosphere. It therefore measures a pressure level and not, in general, an altitude level.

Standard altitude—Pressure—Temperature table

Altitude, feet	Inches, mercury	Pressure, millimeters mercury	Air temperature, degrees Centigrade
−1000	31.02	787.9	17.0
−800	30.80	782.2	16.6
−600	30.58	776.6	16.2
−400	30.36	771.1	15.8
−200	30.14	765.5	15.4
0	29.92	760.0	15.0
200	29.71	754.5	14.6
400	29.49	749.1	14.2
600	29.28	743.6	13.8
800	29.07	738.3	13.4
1000	28.86	732.9	13.0
2000	27.82	706.6	11.0
3000	26.81	681.1	9.1
4000	25.84	656.3	7.1
5000	24.89	632.3	5.1
6000	23.98	609.0	3.1
7000	23.09	586.4	1.1
8000	22.22	564.4	−.8
9000	21.38	543.2	−2.8
10000	20.58	522.6	−4.8
11000	19.79	502.6	−6.8
12000	19.03	483.3	−8.8
13000	18.29	464.4	−10.8
14000	17.57	446.4	−12.7
15000	16.88	428.8	−14.7
16000	16.21	411.8	−16.7
17000	15.56	395.3	−18.7
18000	14.94	379.4	−20.7
19000	14.33	364.0	−22.6
20000	13.75	349.1	−24.6
25000	11.10	281.9	−34.5
30000	8.88	225.6	−44.4
35000	7.04	178.7	−54.3
40000	5.54	140.7	−55.0
45000	4.36	110.8	−55.0
50000	3.44	87.3	−55.0

The altimeter indicates the altitude above a fixed level on the earth, such as sea level, only at the point of take-off. Prior to take-off for a local flight the altimeter is usually adjusted to read zero. It then indicates the altitude, according to the pressure-altitude rela-

tionship, above the pressure level of the point of take off for the time it was set. The atmospheric pressure at this point will change during the flight. For instance, in a time interval of about five hours the pressure level in summer will change on the average about ±100 feet. Unusual conditions will increase this change to ±300 feet. In winter the average change is about ±300 feet and may be

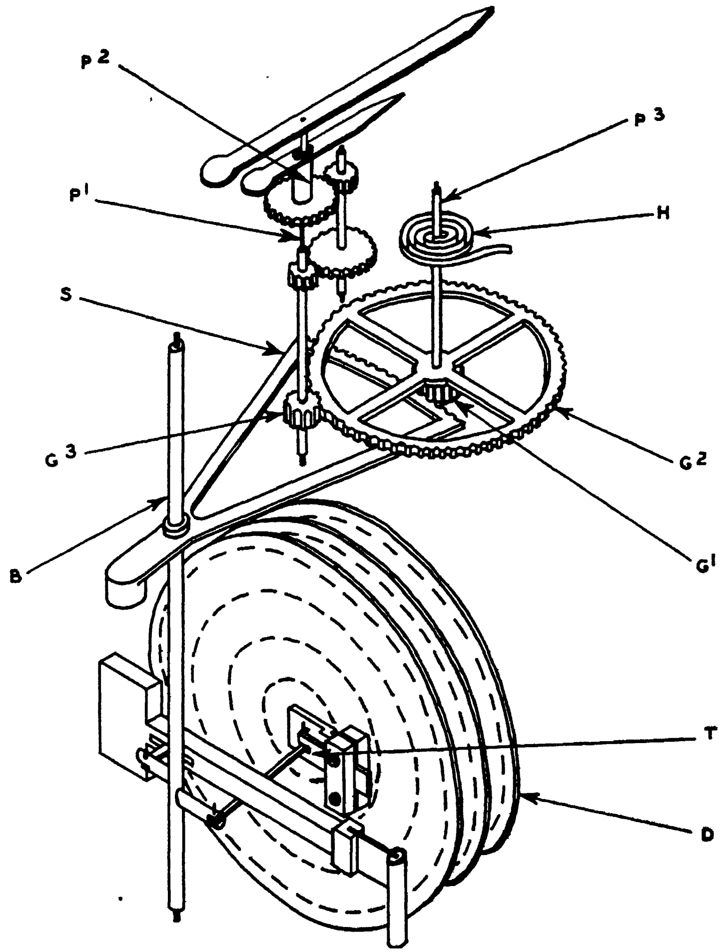

FIGURE 9.—Diagrammatic sketch of sensitive altimeter.

as much as ±1,000 feet. Thus on the return of a five-hour flight the altimeter may and probably will be in error by the amounts given above.

Not only does the pressure change with time, but also with the place. For instance, an aircraft takes off from an airport at sea level and flies to another airport at sea level. The altimeter will be

in error upon landing because of the difference in pressure at the two places even though the elevation is the same. Corrections can be made for these errors, but outside help, such as radio, is required to obtain the pressure level of the airport just prior to landing. The method of making this correction will be discussed later.

The barometric method of measuring the altitude above any base depends on measurements of both the air pressure and temperature as well as other quantities that may be neglected here. If the altitude above the ground level is desired, the indications of the altimeter must be corrected for deviation of the temperature of the air column from that assumed in the standard atmosphere.

A typical altimeter consists of a sealed, evacuated, diaphragm capsule suitably connected by a mechanism to a pointer. The diaphragm capsule will have the maximum force exerted on its outside surface at sea level and any increase in altitude with its lower atmospheric pressure will decrease that force. As a consequence the capsule will expand and this movement transmitted to the pointer will indicate the altitude on a scale calibrated in feet.

The mechanism of one type of sensitive altimeter is shown in figure 9. Three evacuated, pressure-sensitive diaphragm capsules *D* are used to obtain greater sensitivity. As these deflect with changes in pressure a lever connected to the center of the capsules rotates bell crank *B* and in turn sector *S*.

Through gear *G*1, *G*2, and *G*3 pointer shaft *P*1 is rotated at a rate of one revolution for each 1,000 feet change in altitude. Pointer shaft *P*2 on which a shorter pointer is mounted, is rotated through an additional gear train at a rate of one revolution for each 10,000 feet. A third and smaller pointer which indicates the full range of the instrument in one revolution is placed on shaft *P*3. Backlash is taken up by hairspring *H*.

Bimetallic strip *T* compensates for the effect of changes in the temperature of the instrument at one pressure (29.92 inches of mercury). In other types this compensation is made for the entire range of pressures.

The barometric type altimeter is subject to the following errors:

INSTRUMENTAL

(1) *Scale error.*—This is the error in the indication of the altitude corresponding to the pressure in the standard atmosphere. It is due primarily to the imperfect adjustment of the altimeter mechanism to the required relation.

(2) *Friction and vibration error.*—Friction in the mechanism causes (1) irregular motion of the pointer while the pressure is

changing uniformly, and (2) lost motion upon reversal of the direction of pressure change. These effects are eliminated almost entirely if the altimeter is lightly vibrated. Some vibration is essential to obtain satisfactory performance and for this reason no effort is made to provide an instrument panel installation completely free from vibration. It has probably been noticed by the student that when the altimeter is set to zero with the engine idling and then the engine is turned up enough to cause vibration the reading of the altimeter will change. Friction is of course responsible for this error and the student is usually cautioned to set the altimeter while the plane is turning up or to vibrate the instrument by tapping after it is set. Excessive vibration over a period of time will cause the altimeter to change slightly, but the amount of this error is small.

(3) Secular error.—It has been found that the zero setting of the altimeter changes with time and further, that the entire scale-error curve is shifted by the amount of this change. This progressive change in error is known as the secular error and is caused by the release of internal stresses and a drift in the diaphragm capsules. The secular error is such that for most altimeters the reading at a given pressure decreases with time.

(4) Position error.—This error is the change in reading due to the effect of statically unbalanced parts when the instrument is oriented about its principal horizontal axis.

(5) Temperature error.—Temperature error is the change in reading with change in temperature of the instrument. This error (not to be confused with that due to variation of atmospheric temperatures from the standard temperature-pressure-altitude relation) is due largely to the change with temperature of the elastic moduli of the elastic element. Instruments are ordinarily compensated for this error at zero pressure altitude.

(6) Drift and recovery.—There are changes with time in the reading of an altimeter at a given altitude. Of these drift is the increase in reading after the altitude is increased and recovery is the subsequent decrease in reading with time after reducing the altitude to zero or some other definite value.

(7) Hysteresis.—The difference between two readings of an altimeter at a given altitude, the first obtained when the altitude is increasing and the second when it is decreasing is hysteresis. The latter is always the higher. Hysteresis at zero altitude is also known as after effect.

ERRORS INHERENT IN THE BAROMETRIC METHOD

(8) Deviation of the temperature of the air column from that assumed in the standard atmosphere.

(*9*) *Change in the amospheric pressure* at the reference level.

(*10*) *Variations in the elevation* of the surface of the earth.

Errors (*1*) to (*4*), inclusive, are readily determinable for each instrument, and corrections for these errors can easily be applied in flight. The temperature error (*5*) is indeterminate because of the necessity for measuring the temperature of the instrument. The construction of instruments compensated for temperature at all altitudes offers no practical difficulties other than that of increased cost. Errors (*6*) and (*7*) are indeterminate, since they both depend on time and the previous elastic history of the instrument. The errors (*8*), (*9*), and (*10*) can be eliminated only by obtaining information from the ground.

The following table will give the values of the various errors discussed:

Description	Error in feet
(*1*) Scale errors, up to	±50
(*2*) Friction and vibration errors, up to	±15
(*3*) Secular errors in 50 days	−10
(*4*) Position error, up to	±10
(*5*) Temperature error, feet per ° C., up to	± 2
(*6*) Drift in 5 hours at—	
5,000 feet	+25
10,000 feet	+50
15,000 feet	+75
(*7*) Hysteresis, not exceeding	+50
Hysteresis, for small deviations from a given altitude	+10

Several means of adjusting the sensitive altimeter are in operation at the present time. One type has two triangular markers that are rotated by the setting knob. When these markers are placed at zero the instrument is set for standard conditions at sea level. Another type has a pointer on a separate scale, graduated in feet, and when placed at zero the instrument is set for standard conditions at sea level. Another type has a window similar to a speedometer. When 29.92 is set in this the standard sea level setting has been made. This last type of instrument is the only one in which pressure levels other than sea level may be set directly on the instrument. In the first two types the difference between the desired pressure level and the standard sea level pressure must be corrected to feet, according to the standard pressure-altitude relationship, in order that the markers may be correctly set.

Before proceeding with a description of correcting the altimeter it is necessary to have a thorough understanding of pressure altitude. PRESSURE ALTITUDE IS BAROMETRIC PRESSURE EXPRESSED IN FEET OF ALTITUDE ACCORDING TO THE STANDARD SCALE. For example, the pressure altitude for 29.92

inches of mercury is zero. Referring to the standard table, the pressure altitude for 28.86 inches of mercury is +1,000 feet. With the correction scale set on zero or standard conditions, in an altimeter with no instrumental errors, the instrument will indicate the pressure altitude. If there are instrumental errors, these will have to be applied to the indication of the altimeter as corrections to obtain the pressure altitude.

To correct the altimeter for variation in temperature from the normal lapse rate of approximately 2° C. per thousand feet several methods are in use. As will be seen, these are not exact and are only approximations. This temperature error is not an instrument error but is a variable in the quantity the instrument is designed to measure; that is, pressure differentials. The regulations specifying the altitudes to be flown on the civil airways do *not* give effect to this error in altimeters but specify the altimeter is to be set for the standard atmosphere sea level pressure of the locality. No other adjustment is to be made. The main reason for this is that no two pilots would be likely to apply the same correction. Others would make no correction at all. Thus the altitude separation of aircraft making it safe for instrument flight would be considerably reduced and danger of collision would result. As this error is the same in all instruments, the errors will cancel each other if not considered and the desired separation be maintained.

For high altitude precision work it is essential that the indicated altitude be corrected. One method of doing this, using the Mk. VIII computer, and provided the working area is in close proximity to the base, is as follows: Prior to take-off the correction scale of the altimeter is set to the zero reference mark. The indication of the altimeter then corrected for instrumental errors is the pressure altitude. The altimeter is now set to read "zero" and the take-off made. Starting at zero altitude, the air temperature is noted and recorded for every 1,000-foot level up to the operating altitude. The pressure altitude at this level is obtained by applying the sea level pressure altitude to the indicated altitude, corrected for instrumental errors. The average pressure altitude is obtained by taking one-half of this value. This is one argument. From the record of air temperatures the mean of the whole column is determined. This is another argument. The indicated altitude, corrected for instrumental errors, is the third argument.

On the scales provided on the Mk. VIII computer, set the mean air temperature opposite the average pressure altitude. Opposite the indicated altitude on the minutes scale the corrected altitude is read on the miles scale.

As an illustration, take a pressure altitude at surface of +400 feet and air temperatures as follows:

cated altitude corrected for instrumental errors:	*Air temperature*
0	+21° C.
1,000	+19° C.
2,000	+17° C.
3,000	+14° C.
4,000	+11° C.
5,000	+10° C.
6,000	+7° C.
7,000	+6° C.
8,000	+4° C.
9,000	+2° C.
10,000	−1° C.
Total	+110

Air temperature was measured at 11 levels, therefore the mean is 110 divided by 11 or +10° C.

Pressure altitude is 10,000 plus 400, or 10,400 feet. Average pressure altitude is 5,200 feet. The indicated altitude, corrected for instrumental errors, is 10,000 feet.

The Mk. VIII computer is now used in the following manner (as shown in fig. 10):

Plus 10° C. air temperature is set opposite 5,200 feet pressure altitude as shown; the corrected altitude is read on miles scale opposite 10,000 feet on the minutes scale as shown; 10,200 feet, then, is the corrected altitude.

It is suggested in the following problems the student blank off the last column, solve the problem, then check answer.

Average pressure altitude	Mean air temperature	(Corrected) indicated altitude	Corrected altitude	Average pressure altitude	Mean air temperature	(Corrected) indicated altitude	Corrected altitude
4,250	+ 5°	8,000	7,980	8,400	−5°	17,000	16,800
5,750	+2°	11,000	10,900	7,600	−2°	15,000	14,900
4,500	+10°	10,000	10,150	5,600	+1°	11,000	10,900
6,500	+8°	12,000	12,250	8,600	−10°	17,000	16,560
5,500	0	11,000	10,830				

The above solution was dependent on the objective being in close proximity to the base. This same method may be used if the pressure altitude and average air temperature is obtained in the vicinity of the objective. In cases where it is impracticable to obtain the mean temperature the following method may be used: The air temperature at flight level is set opposite the pressure altitude at this level. The corrected altitude is then read in the same manner as before; that is, it appears on the miles scale opposite the figure on the minutes scale that corresponds to the indicated altitude corrected

for instrumental errors. It must be remembered that this is not as correct as the previous method, because the corrected altitude is dependent on the temperature of the whole column of air directly below the plane as well as that at the flight level. An inversion will, of course, cause this method to be seriously in error. Instances have been recorded with below-freezing temperatures existing on the ground, whereas because of inversion the air temperature at six or

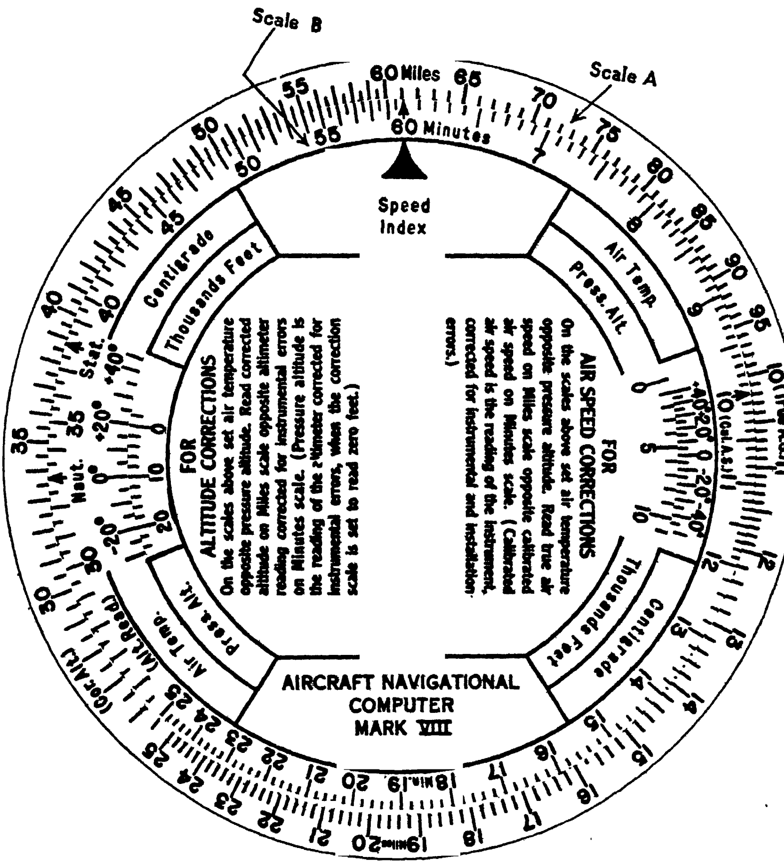

FIGURE 10.—Aircraft navigational computer Mark VIII set for example on page 24.

seven thousand feet was found to be plus 20° C. With conditions of this nature a mean temperature must be taken, and even then large errors may be encountered.

The sensitive altimeter is adjusted for landing by instruments when the "altimeter setting," broadcast in weather reports, is set on the correction scale. In some instruments the correction is applied directly, in others, the barometric pressure must first be changed to feet of pressure-altitude to be applied.

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Air Speed Indicator

In the Naval Service the unit of speed is the "knot," which is equal to 1 nautical mile per hour. Air-speed indicators in the Navy are usually calibrated in knots, while those in use by the Army and some commercial companies indicate statute miles per hour. The face of the instrument shows which speed term applies.

The air-speed indicator, as the name implies, measures the speed of the aircraft through the air. The fact that the density of the air decreases as the altitude increases must be considered in measuring air speed. Therefore, the problem of measuring air speed at various atmospheric pressures is involved, and thus a mere measurement of the head-on air pressure is insufficient. However, by measuring the difference between the static atmospheric pressure and the head-on pressure the effect caused by different pressure levels is partly reduced. To pick up these two pressures the Pitot-static tube is used. A form of Pitot-static tube is shown in figure 11. The Pitot tube opening is shown at *P*, and at *PT* is the line leading from the Pitot tube to the indicator. The hole *H* in *PT* opens into the Pitot tube. The small holes *D* permit water to drain from the Pitot tube and do not change the pressure transmitted to the indicator. Static pressure is obtained in the portion of the tube with holes *S* in its walls, opening into the air stream. This pressure is transmitted to the indicator by the line *ST*. The plug *W* separates the Pitot from the static portion of the tube.

The motion of the Pitot tube through the air creates in the tube a pressure of air whose magnitude is proportional to the square of the air speed. This pressure is transmitted through line *PT* above to one side of a flexible diaphragm mounted in the indicator. Because the pressure in the cockpit of an aircraft fluctuates it is necessary to place the static tube close to the Pitot tube. In figure 11 the filaments of air become parallel to the surface of the tube by the time the static holes at *S* have been reached. Because of the nicety of the holes and their being normal to the tube surface, suction is avoided. Thus the pressure existing in the static tube is a measure of the static atmospheric pressure and is not varied by the air speed. This pressure is led to the other side of the flexible diaphragm in the indicator. Thus the two pressures led to the indicator are (1) the Pitot or head-on pressure that is dependent on the speed through the air and (2) the static pressure dependent on the flight level.

An electrically heated Pitot-static tube is used to insure operation of air-speed meters under ice-forming conditions.

The indicator consists of an airtight diaphragm capsule *D*, in figure 11, and a mechanism for multiplying its deflection. This

mechanism is a bell crank with short arm SA and long arm LA, a sector S, and a pinion P, which is on the pointer shaft. A hair-spring H secured to the pointer shaft and to the instrument case holds SA against the diaphragm bridge B through the multiplying mechanism shown. The entire mechanism is housed in an air-tight case, with the Pitot tube connected to the inside of the dia-

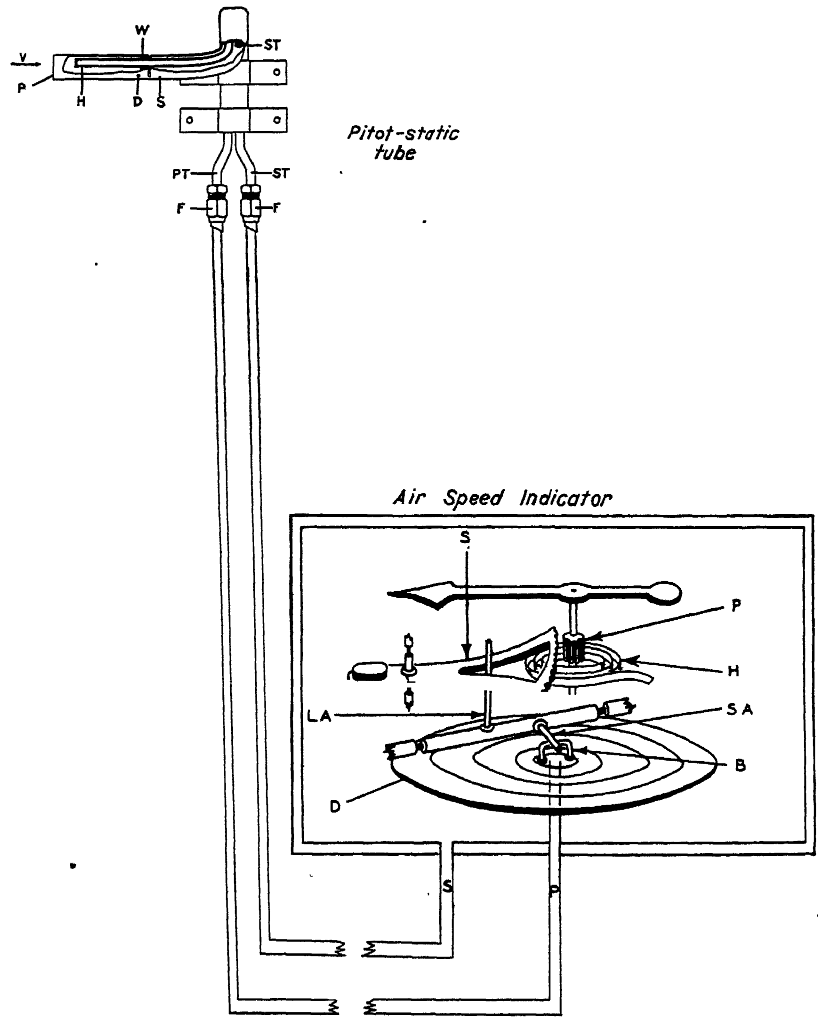

FIGURE 11.—Diagrammatic sketch of an air-speed indicator installation.

phragm and the static tube to the case. The resultant pressure acting on the diaphragm capsule is the difference between the Pitot and static pressures. An increase in speed causes the diaphragm to expand and vice versa.

CALIBRATION

There are three kinds of air speed, namely:

(*a*) *Indicated air speed* is the air speed as shown by the air speed indicator. This has all the errors of the instrument as well as the errors caused by temperature and pressure being other than normal.

(*b*) *Calibrated air speed* is the indicated air speed corrected for all errors other than those caused by temperature and pressure. For standard conditions of pressure and temperature the calibrated air speed and true air speed are the same.

(*c*) *True air speed* is the actual speed of the aircraft relative to the air. The true air speed is obtained by correcting the calibrated air speed for temperature and altitude (pressure).

The navigator's problem is to determine the ground speed. This is usually done, as will be discussed later, by the vector addition of the true air speed and the wind. Thus it is seen the true air speed must be obtained. As this is only available from the indicated air speed, it is necessary to know the correction to be applied.

The installation must first be checked by calibration with a standard instrument for leaky cases, deformed diaphragm, and correctness of calibration. A simple method of doing this is by use of the installation shown in the diagrammatic sketch in figure 12.

Following through the sketch it is seen the pressure is increased by advancing the rollers along tube. This is done until the calibrated or standard indicator (known to be without instrumental error) indicates 60 knots. A man in the cockpit reads the indicator at that place. The rollers are held in this position, and if the indicators maintain a steady reading there is no leak in the system. If not, the system must be checked and leak repaired. Next the pressure is increased and readings taken for every 10 knots. If any large errors are encountered the indicator should be sent to the instrument shop and replaced with another one. When all possible corrections have been made and the errors are of small magnitude, the indicator in the aircraft is ready for calibration over a speed course.

This should be done over an established speed course, which is at least 2 miles long, level, and suitably marked to permit accurate estimation of the time of starting and finishing the runs. Preferably a no-wind condition should exist, but as this is seldom attainable it is satisfactory if the course parallels the wind. Runs are made up and down the course and the average taken. This offsets the effect of the wind, because in one case the ground speed is greater than the air speed by the amount of wind, but on the return it is less by the same amount. Thus the average ground speed is true air

speed. The runs should be made as low as possible (less than 50 feet) in order that the conditions of the test may be those of sea-level barometric pressure and temperature. It is essential that the indicated air speed be kept constant throughout the run, and for this reason the aircraft should be steadied down before passing the markers. It is more important to maintain constant indicated air speed than it is altitude or engine speed. The barometric conditions and the air temperature must be recorded for each flight. Since the errors may not be constant throughout the range of the instrument, it is desirable to make runs at various indicated air speeds, usually every 10 knots, particular emphasis being placed on the runs in the cruising range.

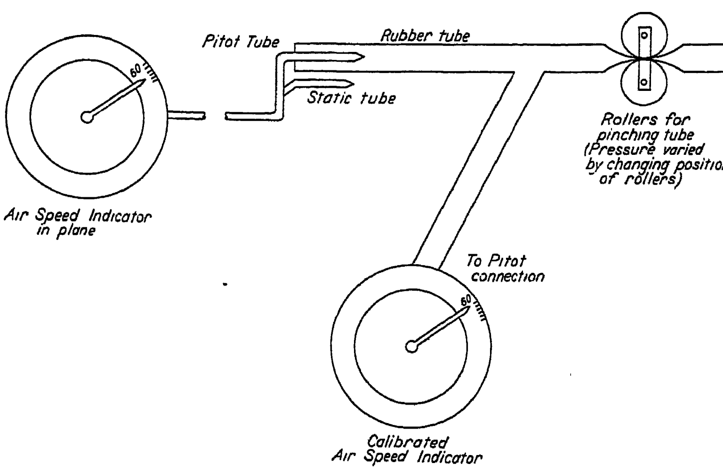

FIGURE 12.—Installation for checking air-speed indicator.

The conditions of the test will seldom duplicate the standard conditions, so a correction must be applied to the true air speed in order to convert it to calibrated air speed. The following formula may be used for this conversion:

$$Vt = Vc\sqrt{\frac{Th \times Ps}{Ts \times Ph}}$$

Where Vt=True air speed:
Vc=calibrated air speed.
Th=absolute temperature at own altitude.
Ts=standard absolute temperature.
Ph=pressure at own altitude.
Ps=standard pressure.

If the temperature and altitude of the test remain the same, a constant can be derived for the above formula and $Vt=CVc$. In order to obtain the error of the instrument, the ground speed of

the trials converted to calibrated air speed in the manner just described must be compared with the indicated speed. The ground speed in knots is equal to the length of the course, measured in nautical miles, divided by the elapsed time in hours.

From the data obtained a table can be compiled showing the error of the instrument. It is often practical to compute this error for one aircraft and then compare other aircraft with the calibrated one by flying in formation with it. This table is entered on the calibration card for the airspeed indicator and may be in the following form, figure 13.

Calibrated *AS*	60	70	80	90	100	110	120	130	140	150	160	170	Etc.
Indicated *AS*	60	72	84	96	106	114	122	130	138	145	154	164	

FIGURE 13.

After the method of correcting indicated air speed to obtain calibrated air speed and vice versa is thoroughly understood, the next step is correcting the calibrated air speed for temperature and altitude to obtain true air speed. The Mk. VIII computer offers the accepted means of doing this and will be explained here. To solve for true air speed three quantities are needed:

(1) Air temperature at altitude level of flight (obtained by reading air thermometer on strut).

(2) Pressure altitude (obtained by setting the correction scale of altimeter to zero and correcting the reading for instrument error. Pressure altitude is desired because the density of the air and not the altitude above the surface affects the air-speed indicator).

(3) Calibrated air speed.

On the appropriate scales, set air temperature opposite pressure altitude. Read true air speed on miles scale opposite calibrated air speed on minutes scale.

Pressure altitude, 3,000 feet; air temperature, +18° C.; calibrated air speed, 110 knots. What is the true air speed?

Referring to figure 14, the method of setting the computer is self-explanatory. The true air speed is 117 knots.

It may be seen also that having the true air speed, pressure altitude, and air temperature, the calibrated air speed may be found. Using the same pressure altitude and air temperature as in the above problem, and knowing the true air speed to be 117 knots, the calibrated air speed is read on minutes scale and found to be 110 knots.

Below is given a list of problems which may be solved by the student. Use the calibration card in figure 13 for correcting between indicated air speed and calibrated air speed.

Indicated air speed	Calibrated air speed	Air temperature	Pressure altitude	True air speed
70	68	+35	2,000	73
114	110	+10	9,000	129
83	79	−11	10,000	91
94	88	−27	10.500	99
105	99	−5	5,000	105
73	71	−5	9,500	82
84	80	+5	5,500	87
130	130	−24	11,000	149
118	115	−18	6,000	121
126	125	−9	8,000	139
111	106	−12	16,000	137
125	124	−39	29,000	201

In case a Mk. VIII computer is not available the following thumb rule may be used: True air speed exceeds the calibrated air speed by 2% per thousand feet pressure altitude. It must be remembered this is not exact and at times may cause an appreciable error.

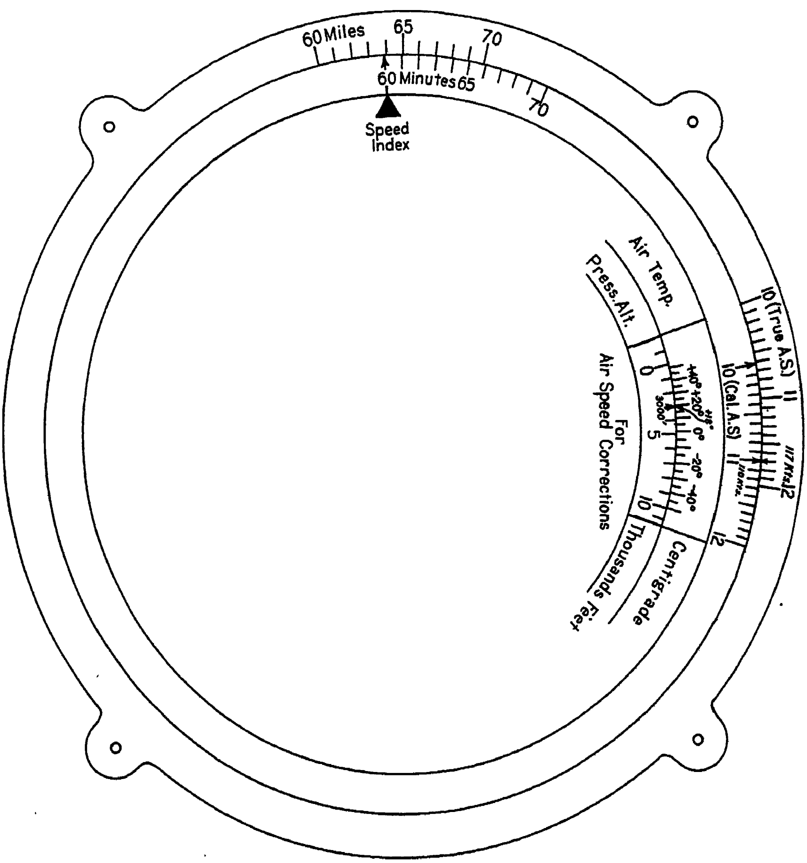

FIGURE 14.—Aircraft navigational Mark VIII computer set for example on page 30.

GROUND SPEED

The usual method of finding ground speed is by adding the true air speed and true heading vector of the aircraft to the wind vector.

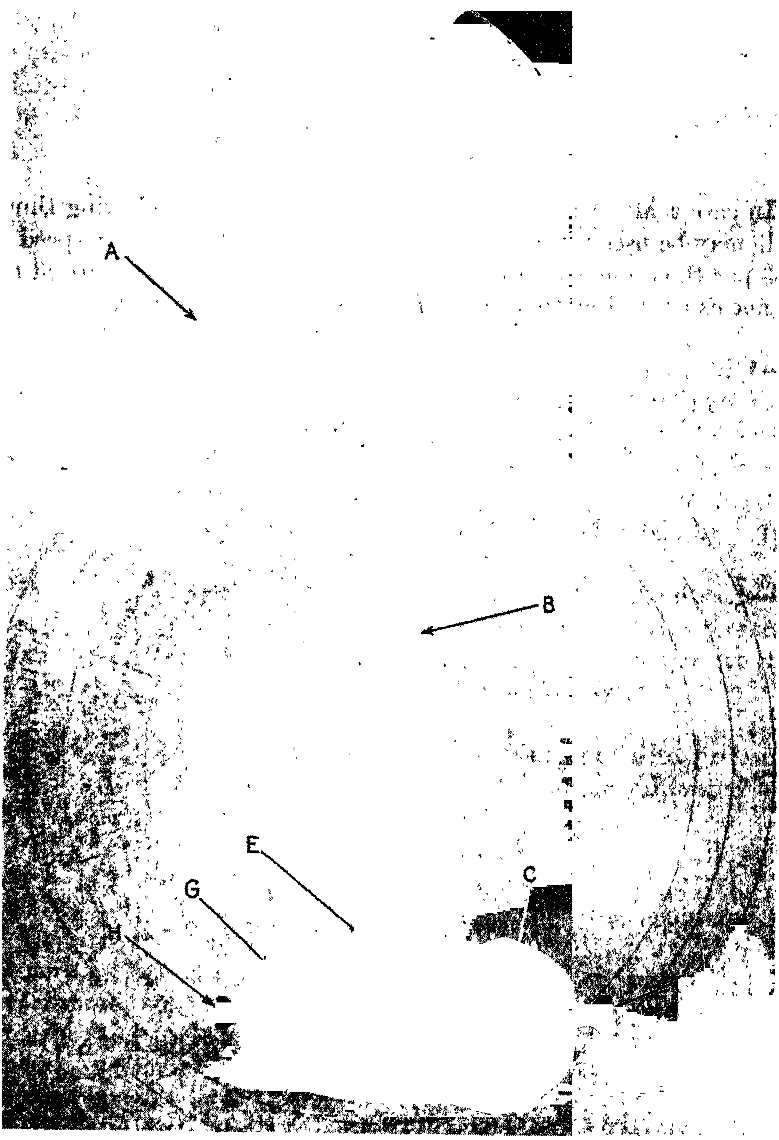

FIGURE 15.—Mark IIB pelorus drift sight.

The result will give the ground speed and track the aircraft is making good over the ground. The true air speed is determined by correcting the indicated air speed as described. The true heading is obtained by

correcting the compass indication as will be discussed later. The other quantity, the wind, is obtained by use of the drift sight.

Figure 15 shows the present standard pelorus drift sight Mark IIB. The sighting tube *A*, support tube *B*, and pointer *C* constitute one assembly. Two base plate assemblies *F* are provided, one for each side of the airplane. In the base plate the sighting tube assembly is secured to the base plate by pulling on the pin *J* which allows the assembly to be inserted in the base plate. Releasing the tension on pin *J* allows it to settle in the groove holding the assembly in place but allowing it to be turned.

Assembled pelorus ring *G* is rotatable through 360°, being locked by stud *H*. This provides for setting the ring to indicate true, relative, or compass bearings.

The pointer *C* has two reference points, the inner one being a wire for reading the bearing on the pelorus ring, the outer one being a mark for reading opposite the drift scale. The drift scale is fixed in relation to the thrust line of the plane and graduated in single degrees from 0 to 40 left and right. One side of the scale is marked plus, the other minus.

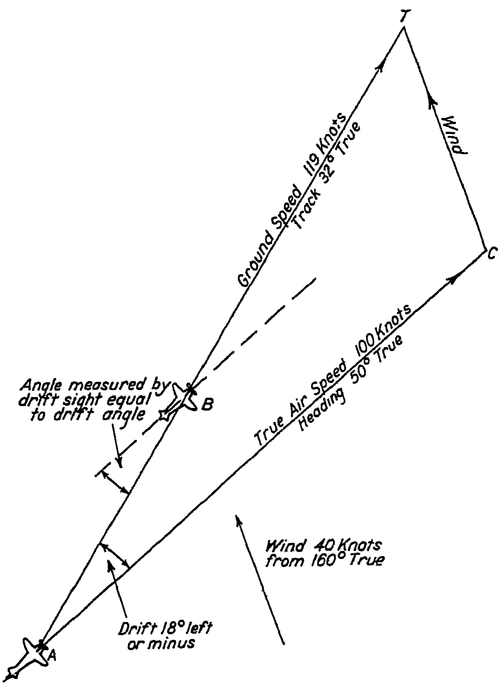

FIGURE 16.—Illustration of drift angle.

The support tube is adjustable in height, sliding through the collar and being locked by the stud at *E*.

Open vane sights are provided on the top side of the sighting tube to permit the observer to locate his objects before using the small aperture in the sighting tube.

The drift sight is used to measure the drift of the aircraft caused by the wind. Referring to figure 16 an object directly below the aircraft at *A* is used for the observation. If over land this is some landmark, if over water a smoke bomb is dropped at this point. *AC* represents the true heading of the aircraft, which in this case is 50° T. *AC* in length represents to scale the true air speed of the aircraft, in

this case 100 knots. It is absolutely essential while taking the sight that the speed and course be held constant. Because of the wind the aircraft will not move along *AC*, but with a wind of 40 knots from 160° T it will be blown to the left of this heading and move along the track *AT* which is 32° T. When the aircraft reaches point *B* which is any point along line *AT* the drift sight is taken by sighting at object at *A* through the drift sight. The reading of pointer *C* of the drift sight is 18° minus or left as shown. This is the drift angle.

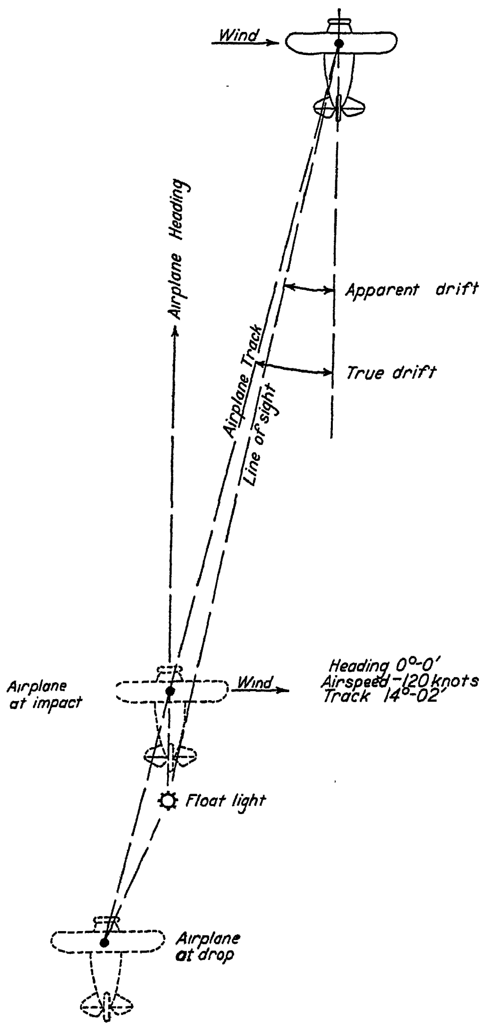

FIGURE 17.—Cross trail of float light.

Errors in drift observations by float lights, due to cross trail.—When an airplane heading is constant and the wind is steady, a float light dropped from the airplane hits the water directly behind. The float light will be on the track of the airplane only if there is no drift.

An example of cross trail showing the relative positions of the airplane and float light is shown in figures 17 and 18. For this example a true heading of north, a true airspeed of 120 knots, a wind of 30 knots from west, and an altitude of 8,000 feet are taken. For this set up the float light will hit the water approximately 1 nautical mile astern of the airplane.

The float light does not begin showing smoke or light until about 15 seconds after the impact on the water. The surface distance of the airplane from the float light when the latter hits the water (not when it ignites) is the distance which determines the error in the drift angle, as shown in figure 18.

The true drift angle is 14°02′. In figure 18 the apparent drift angles, observed as relative angles with such a drift sight as the Mk. II–b, are shown at *a*, *b*, *c*, and *d* at the end of 1, 2, 3, and 4 minutes from the time of the float light impact. The air distances covered are respectively 2, 4, 6, and 8 nautical miles. Airplane positions are respectively *A′*, *B′*, *C′*, and *D′*.

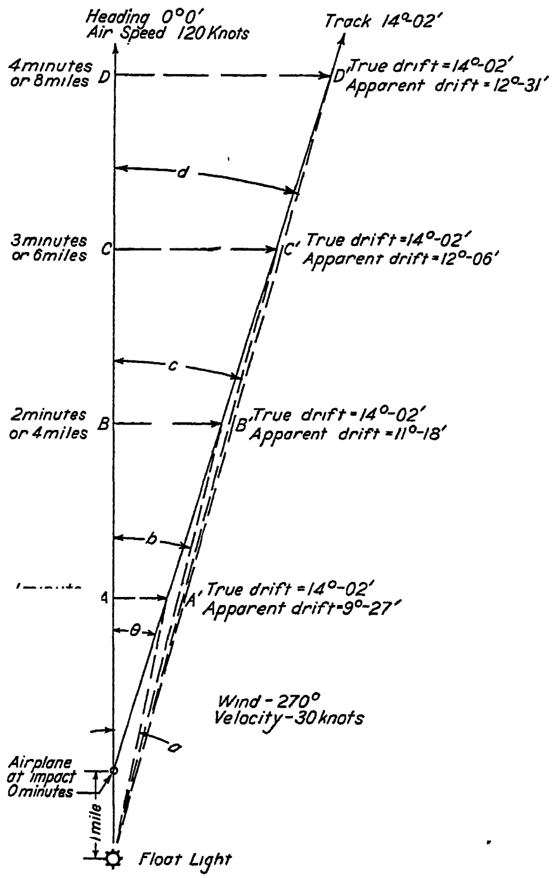

FIGURE 18.—Drift error due to cross trail.

It should be clear from the diagram that the drift observations should be made at the latest possible time in order to have the apparent drift as close as possible to the true drift.

This cross trail error is apparent only when using the Mk. II–b drift sight or similar method of observing a relative bearing. The error is always additive and depends upon the speed, altitude, and drift of the airplane. It is recommended that, at altitudes of more than 5,000 feet and drift of more than 10 degrees, a flat correction of plus one degree be applied to the observed drift.

After the drift angle is thoroughly understood the student is ready to proceed with its solution to obtain the wind. There are two methods of doing this i. e., the one speed two course or "wind star" method and the two speed one course method. The former is the one in use today and will be discussed here.

The results of taking "wind stars" show that with practice the direction of the wind can be determined within ±20° in direction and ±3 knots in velocity.

The results of wind determination both in an airplane and by balloon observation from the ground show that at times the wind may vary in direction by 35 degrees and in velocity by 9 knots.

As the name infers the one speed two course method makes use of a drift sight on each of two different headings at the same airspeed. Taking these two drift sights the following information is obtained.

	First sight	Second sight
Heading True	045°	315°
Airspeed True	110 K	110 K
Drift	[1] 15°	[2] 10°

[1] Plus or right. [2] Minus or left.

With the above information the Mk. III plotting board may be used to solve for the wind. Referring to figure 19 $WP1$ is the first heading and airspeed as shown. The drift angle of 15° plus or

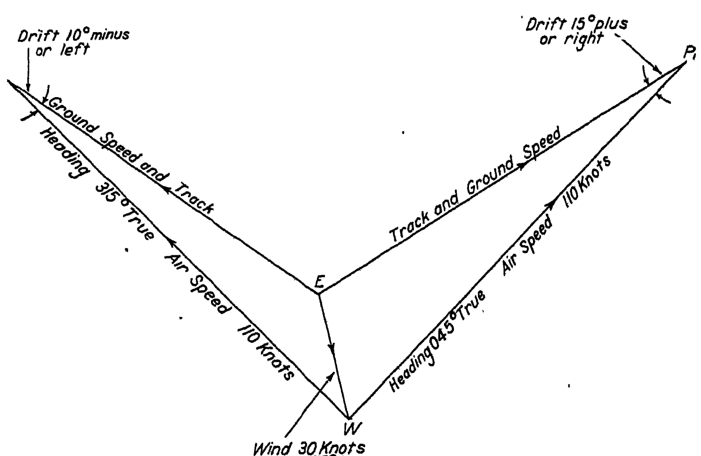

FIGURE 19.—Double drift method of solving for wind.

right is used to determine the track $P1E$ which is drawn as a solid line of indefinite length. The second heading and airspeed is represented by the line $WP2$. Using the drift angle of 10° minus or

left the second track $P2E$ is drawn. It is drawn long enough to intersect $P1E$. A line is drawn from point of intersection E to the center of the board W. This represents the force and direction of the wind. Measuring this wind using the true index we find it to be force 30 knots from 347°T. As the wind is usually different at the different altitudes it must be remembered that THIS IS THE WIND AT THE ALTITUDE OF THE AIRCRAFT WHEN THE DRIFT SIGHTS WERE TAKEN.

The use of the Mk. III plotting board in solving two drift sights for wind as well as solving the true heading, true airspeed, and wind for track and ground speed will be further discussed in a later chapter. The actual use of the drift sight in taking a drift indication, together with an understanding of the drift angle is all that is required at this point.

Among other methods of determining ground speed are, (*a*) plotting of successive positions on a chart, noting time over each and calculation of run between, (*b*) runs over a measured course, (*c*) neutralizing apparent motions of objects on the ground by rotating telescopes and similar devices.

Rate of Climb Indicator

The rate of climb indicator shows the rate at which an aircraft is ascending or descending. It does not indicate the angle of the aircraft to the horizontal, but it is operated by the rate of change of atmospheric pressure which accompanies change of altitude. In other words it shows the vertical component of the speed of the aircraft.

The purpose of the rate of climb indicator is to show the pilot whether he is maintaining level flight or the rate at which he is ascending or descending. This is especially important under conditions of poor visibility as in fog, clouds, or at night.

The rate of climb indicator is a sensitive differential pressure gage and differs from the sensitive altimeter in that it measures the rate of change of atmospheric pressure rather than the atmospheric pressure.

Figure 20 shows a schematic diagram of a typical instrument. The indicator consists primarily of an airtight diaphragm assembly (*D*), and a simple auxiliary mechanism (*B*), for temperature and altitude compensation. The entire mechanism is housed in an airtight case. The static line (*V*) is connected to the interior of the diaphragm and the capillary tube (*C*) connected to the same line, dampens the rate of pressure balancing of the interior and exterior of the diaphragm. The capillary tube (*C*) is a glass tube with a small bore, which restricts the flow of air.

As the aircraft starts to climb it immediately enters air of lower pressure. This decrease in pressure is transmitted immediately to the inside of the diaphragm through the static tube at (*V*). The pressure inside the case of the instrument, which is the pressure on the outside of the diaphragm, is restricted from changing immediately by the capillary tube (*C*). Therefore the pressure on the outside of the diaphragm is greater than that on the inside and thus the diaphragm will contract. This contraction will move the multiply-

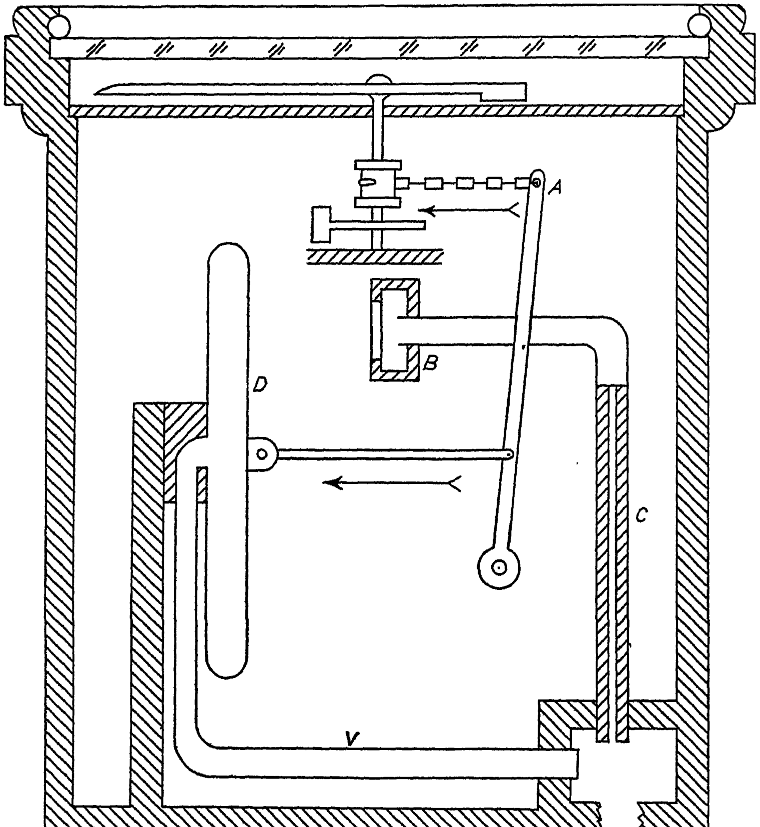

FIGURE 20.—Diagrammatic sketch of a rate of climb indicator.

ing mechanism as shown by the arrows. This will deflect the needle and the instrument will indicate the rate of climb. The capillary tube will allow the pressure to change as rapidly as the aircraft is climbing or descending, but this will lag behind the pressure inside the diaphragm an amount dependent upon the rate of ascent or descent. For instance if an airplane is climbing at the rate of 1,000 feet per minute the pressure on the inside of the diaphragm changes as rapidly as the atmospheric pressure. The pressure on the outside

of the diaphragm is restricted in changing rapidly by the capillary which restricts the flow of air from the case. Now as the pressure in the case becomes greater the flow of air through the capillary is increased. The pressure in the case is increased until it will force the flow of air through the capillary at a rate sufficient to cause the pressure to be dropping as fast as the atmospheric. This pressure difference is calibrated as 1,000 feet per minute. When the aircraft levels off the atmospheric pressure is constant so the pressure on the outside of the diaphragm will catch up and equalize with that on the inside and the pointer will return to zero.

When the aircraft descends similar action takes place except that the high and low pressures are reversed. Instead of the air being forced out of the case it will flow in the opposite direction through the capillary tube into the case. In the latest version of the rate of climb indicator the performance characteristics have been greatly improved and the instrument simplified by outstanding development work with the mechanism, diaphragm, and leak system. The precision mechanism is thoroughly jeweled and balanced. The instrument is extremely sensitive and free from lag; small deviations from level flight as well as rapid changes of altitude are immediately shown. Flight tests have shown that even under the most extreme maneuvers, the indicator shows very closely the actual conditions. However, it is in the normal range of climb and descent used in everyday operations, and as a level flight indicator, that this instrument proves itself an invaluable aid to the pilot.

Direction Indicating Instruments

The first marine instrument invented to aid navigation was the compass. The most accurate methods of position finding are of little practical value unless coupled with a direction indicator to show the course to the destination. Marine navigators always depend for safety in navigation on the "compass, log, and lead." In terms of aviation it is called "compass, ground speed, and altimeter," but note that in each case the compass comes first.

The aircraft compass is a direction indicator depending on sources for its directional impulses either natural and permanent, on one hand, or man made and transient, on the other. In the first group we have the magnetic and gyroscopic compasses, the earth inductor compass, and in some special cases the so-called sun compass. The second group includes such mechanical devices as the radio compass and the radiobeacon which are not actually compasses, but indicate specified directions.

Compasses of the first group are important because of their universal application and reliability in operation. The magnetic com-

pass is most commonly used because of its low cost, availability, simplicity, and ease of operation and maintenance. The other types, with the exception of the gyroscopic, are encountered with increasing frequency, most often in individual aircraft that are attempting some pioneering mission.

Because no completely satisfactory compass for aerial use has as yet been developed, research is needed with a view to improving this instrument. The eventual type will no doubt be gyroscopic in principle although restrictions imposed by size and weight have made the problem difficult of solution.

Because most aircraft compasses depend upon magnetism for their direction force, a brief study in review, should be made elsewhere of the subject of elementary magnetism and the earth's magnetic field.

Variation.—The magnetic pole differs in position from the geographical pole. The magnetic compass will not always indicate true direction, but will differ by an amount dependent upon the angle between the geographical pole and magnetic pole at the position of the observer. The *variation* of the compass is the amount of this angular difference. The observer's true meridian is the arc of a great circle that passes from the true north pole through the zenith thence through the true south pole. The direction of the magnetic meridian is the direction assumed by the compass when acted on solely by the earth's magnetic field. Variation is easterly when the compass points eastward of true north, and westerly when it points westward of true north.

Figure 21 illustrates the variation at San Diego, Pensacola, Savannah, and Norfolk. It can be seen that at San Diego, the variation is easterly, because the magnetic north pole bears to the eastward of the true north pole, and the amount is 15 degrees. At Pensacola the variation is still easterly, but of lesser amount than at San Diego because the magnetic and true poles are more nearly in line. At Savannah there is no variation because the magnetic and true meridians coincide at that point. At Norfolk the variation is westerly because at that point the magnetic north pole bears to the westward of the true north pole.

A study of figure 21 shows that the variation is dependent on position only and remains the same for all headings.

Variation undergoes annual change. The variation is shown on a chart for a given place and time with the amount and direction of the annual rate of change. Figure 22 shows variation lines in different parts of the world. Each line connects all points of equal variation.

Variation changes with time and place, therefore, it is imperative for the navigator to know the variation for the time and place in question. Variation will not generally change more than about 2° in a 100-mile east-west flight and much less in a north-south flight.

Suppose at San Diego, where the variation is 15° E. you desire to head the plane on 15° *T*. If the compass indicated true north the

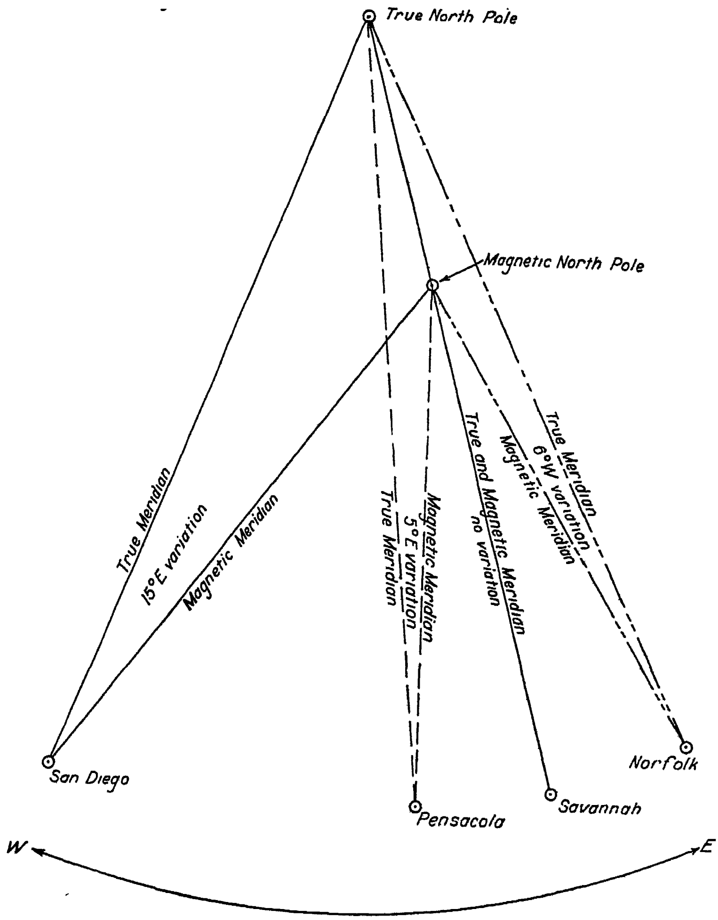

FIGURE 21.—Illustration of magnetic variation.

problem would be a simple one of swinging the aircraft's head until the compass reads 15°. Since the compass is influenced by variation, a variation of 15° E. pulls the compass 15° to the right or east of true north and when flying on heading 15° *T* the compass indicates 0°. Thus by adding the variation of 15° E. to the magnetic indication of 0° the true heading of 15° *T* is found. Suppose now you have a variation of 15° W. The compass would be pulled 15° to the west

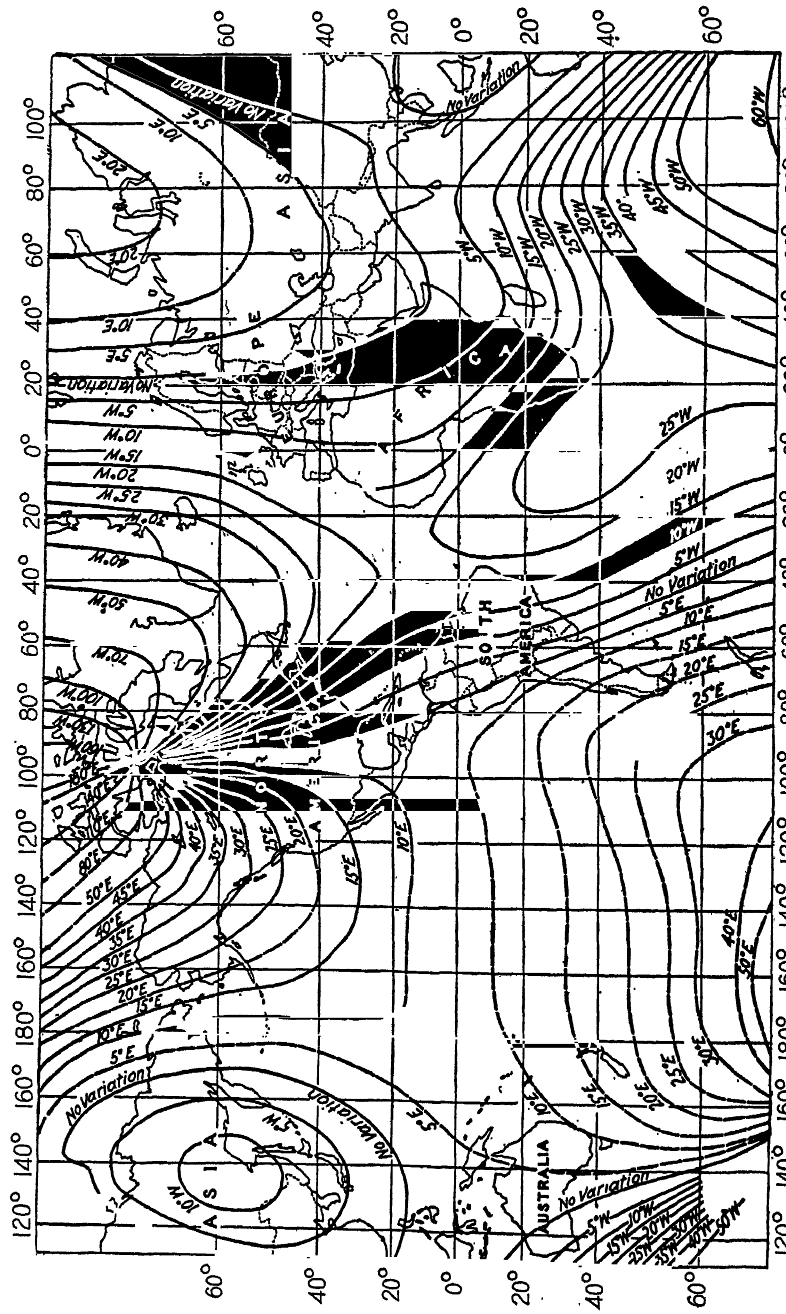

FIGURE 22.—Lines of equal magnetic variation.

or left of true north so to steer a heading of 15° *T*, it is necessary to steer a magnetic heading of 30° *M*. Westerly variation is then subtracted from the magnetic heading to obtain the true heading. Serious error occurs when the variation is applied in the wrong direction. For instance at San Diego, where the variation is 15° E., if it is applied in the wrong direction an error of 30° will result. The pilot should understand the rule for applying variation so well that he will always apply it in the proper direction.

After the effect of variation on the compass is understood a convenient rule for use in correcting magnetic heading to true heading is: "When correcting add east."

Always consider the magnetic heading as incorrect as it must be corrected for variation errors. Thus the true heading may be considered as correct. In applying the above rule to correct magnetic to true add easterly variation. Naturally if the variation is westerly you subtract.

Now going from true to magnetic, you have to "uncorrect," or, our rule is just the reverse, namely subtract east and add west. If you keep this rule in mind at all times you will never err in applying variation.

Below is given a table with a few of the conversions completed and with several to be worked out if desired.

Magnetic	Variation	True	
056°	13° E	069°	Correcting 056° M the 13° E is added.
148°	10° E	158°	Correcting 148° M the 10° E is added.
063°	1° W	062°	Correcting 063° M the 1° W is subtracted.
003°	18° W	345°	Correcting 003° M the 18° W is subtracted.
True	**Variation**	**Magnetic**	
069°	13° E	056°	Uncorrecting 069° T the 13° E is subtracted.
158°	10° E	148°	Uncorrecting 158° T the 10° E is subtracted.
062°	1° W	063°	Uncorrecting 062° T the 1° W is added.
003°	18° W	021°	Uncorrecting 003° T the 18° W is added.

Magnetic	Variation	True	Magnetic	Variation	True
223°	5° W	------	------	16° E	195°
228°	3° E	------	------	10° W	312°
170°	21° W	------	------	11° E	257°
358°	23° E	------	315°	------	330°
234°	15° E	------	314°	------	328°
009°	2° W	------	352°	------	008°

A bar magnet, if free to turn, would align itself parallel to the lines of force of the earth's magnetic field. When it is in this position the total force of the earth's magnetism acts to direct the bar

magnet. This force, like any other directed force, can by the principles of elementary mechanics be resolved into its horizontal and vertical components, as shown in figure 23. Now since the magnets of a magnetic compass are free to turn only about a vertical axis, that is, since they must remain in a horizontal plane, they are acted upon only by the horizontal components of the earth's total magnetic force. This horizontal force, H, is therefore called the directive force.

In addition to the correction for variation, local magnetic disturbances of the compass needle due to magnetic rocks and other material are observed on land and under the sea in many parts of the world and affect all compasses passing over them.

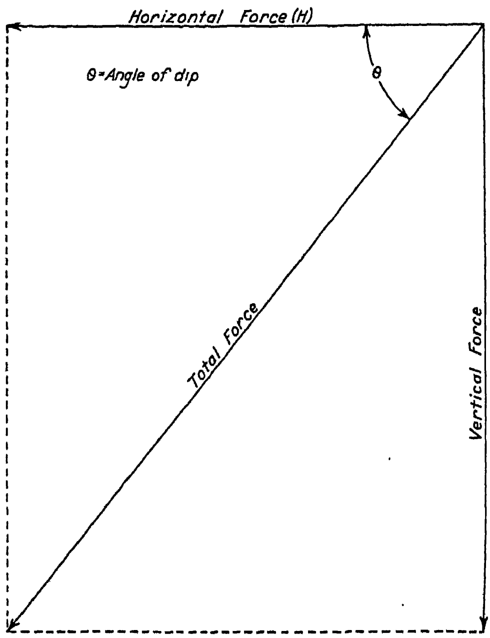

FIGURE 23.—Directive component of earth's magnetism.

Deviation.—The magnetism in an aircraft will affect the compass and cause the compass needle to be deflected from pointing toward magnetic north. The angle by which the compass needle is deflected from the direction of magnetic north by this local magnetism is known as *deviation.* The deviation varies with each direction in which the airplane is headed, but it can and should be corrected, so that the compass will read within 1° to 3° of the proper magnetic heading.

Practically all iron or steel metal in aircraft will be magnetized by induction to a certain extent. There is not usually much iron and steel in the wings, and it is well removed from the compass. The bulk of the steel in the ordinary type of aircraft is forward of the pilot, and it is there that most of the magnetism will be found. The hard iron in the structure may be magnetized by hammering and riveting in manufacture and by vibration in the earth's magnetic field. Thus, if an aircraft were built pointing north, a fore-and-aft bar of hard iron would be magnetized so that its forward end was a

north-seeking or red pole. If built pointing south, the bar would be magnetized so that it would have a blue or south-seeking pole forward. If the aircraft were built on an east-and-west heading, the bar would have practically no magnetism, and what little magnetism was induced would be red on the north side of the bar and blue on the south side of the bar. Thus, if the direction of the aircraft in building is known, it is possible to know in a general way where its red and blue poles will be.

Soft iron is liable to give more trouble than hard iron, because the magnetic polarity may change as the aircraft varies its course. A horizontal soft iron bar placed fore and aft in the plane would be temporarily magnetized by induction, so that it would have a red pole forward when the aircraft is headed north, a blue pole forward when the aircraft is on a southerly course, and very little magnetism when headed east or west. However, little soft iron is found in the modern aircraft, and, vertical soft iron is so rare that it need not be considered.

The aircraft usually carries a great deal of magnetic material in fairly close proximity to the compass. Engines, generators, magnetos, ammeters, radio apparatus, and electric currents set up powerful magnetic fields which may vary considerably in intensity and direction. It is evident that the conditions in an aircraft cockpit are unfavorable for a magnetic compass, and that its position should be chosen with the greatest care.

As most of the magnetic metal is forward of the compass the blue pole will also be forward of the compass. Using as an illustration an aircraft built on a north heading and referring to figure 24 it can be seen that when the airplane is headed north the blue pole of the aircraft will attract the north-seeking pole of the compass, as shown, and hold the compass more strongly on north than usual.

When the aircraft is headed east the compass magnets should lie directly athwartships, but the blue pole of the aircraft will pull the north end of the compass to the east and cause an easterly deviation, so called because the compass needles have been pulled to the eastward.

When the aircraft is headed south the blue pole of the aircraft will repel the south-seeking pole of the compass, and weaken the effect of the earth's magnetism and cause sluggishness of the compass, but will not directly cause any deviation.

When the aircraft is headed west the compass needles should again be athwartships, but the blue pole of the aircraft will pull the north end of the compass to the west this time and cause a westerly deviation.

Referring again to figure 24, it can be seen for westerly deviation the compass will read more than the magnetic heading of the aircraft, so the deviation must be subtracted from the compass heading to get the magnetic heading. In the case of easterly deviation it can be seen that the compass reads less than the magnetic heading. In this case the deviation must be added to the compass heading to obtain the magnetic heading.

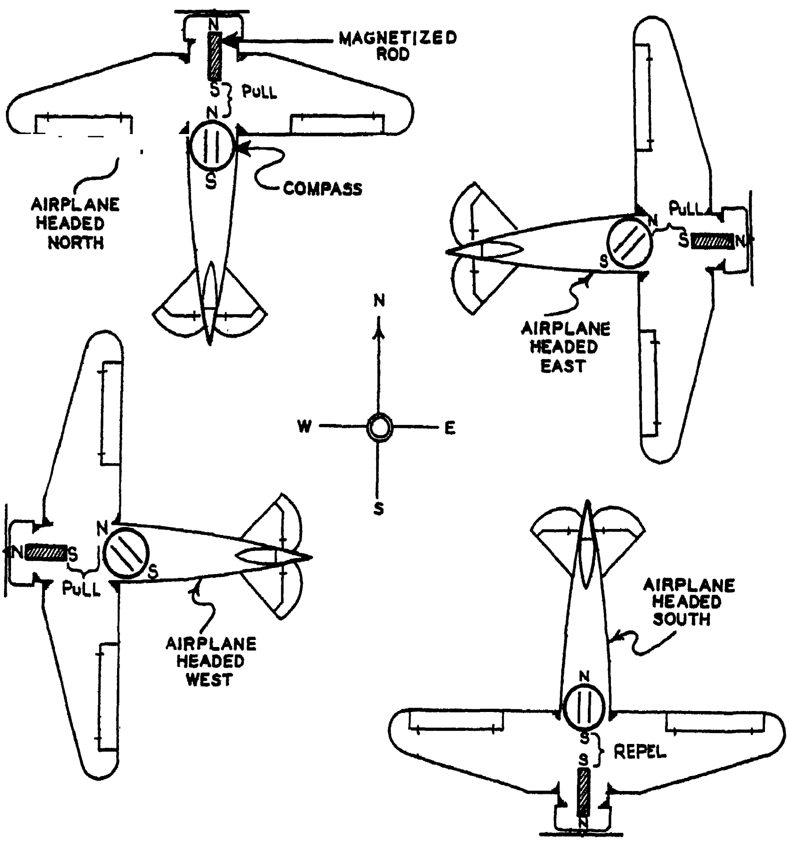

FIGURE 24.—Effect of magnetism induced in hard iron.

After the effect of deviation on the compass is understood the same rule that was used for variation may be used to correct the deviation. In this case the compass heading has both deviation and variation errors, whereas the magnetic heading has only variation error.

Below is given a table with a few of the conversions completed and with several to be worked out if desired:

Compass	Deviation	Magnetic	
059° 020°	3° W 1° E	056° 021°	Correcting 059° C. the 3° W. dev. is subtracted. Correcting 020° C. the 1° E. dev. is added.
Magnetic	**Deviation**	**Compass**	
148° 228°	4° E 2° W	144° 230°	Uncorrecting 148° M. the 4° E. dev. is subtracted. Uncorrecting 228° M the 2° W. dev. is added.

Compass	Deviation	Magnetic
237°	3° W	--------
178°	1° E	--------
319°	3° E	--------
--------	3° W	246°
--------	2° E	315°
--------	3° W	314°
354°	--------	352°
002°	--------	358°

The most commonly encountered types of magnetic compasses for aerial use have the following general features of construction: A rotating system consisting of the card, float chamber (in the liquid damped type), magnetic element, and bearing member; the bowl which consists of the container, damping medium, expansion chamber, lower bearing member, lubber's line, observation windows, illuminating device, compensating device, and the mounting support.

The card acts in the triple capacity of carrier and supporter of the magnetic elements, supporter of the pivot, and bearer of a scale for the reading of headings. Reading scales, arranged either horizontally or vertically, or both, may be provided on the compass card, although the present tendency is toward a scale that can be read from the horizontal plane. With the horizontal-reading card, it is possible to locate the compass at the approximate eye level, which is highly desirable at all times and an absolute necessity if the aircraft in question is to be used under weather conditions that might possibly necessitate instrument flying. For night use, the scale markings should be self-luminous to permit the reading of the compass heading in case of failure of the illuminating device. At present the standard card is provided with a scale graduated every 5°, which enables a pilot of average skill to steer a heading within 2° of that desired.

To maintain the card in the horizontal position despite the tendency of the vertical component of the earths' magnetic field to depress the northern side of the card, a small mass sufficient to neutralize this tendency is attached to the southern side of the card (in the Northern Hemisphere).

The magnetic elements of the compass, supplying the directive force, are usually formed of small flat, or cylindrical, magnetized needles or rods, 2 to 12 in number. Ordinarily, they are constructed from an alloy steel specially hardened. In certain types they are suspended upon wires below the card but usually are attached to the card either within the float chamber or upon its lower surface. Various dispositions are possible, each of which has a different influence upon the action of the rotating system. The selection of particular disposition is based upon the operating requirements of the compass. The moment of inertia of the rotating system, its magnetic moment, and in turn the period of the compass, are all dependent to a certain extent upon the size, number, and position of these magnetic elements. In compasses where the magnets are surrounded by a damping fluid having a corrosive effect upon steel, these elements are coated with a protective metal.

The primary function of the compass bowl is the holding of the damping fluid. It is usually cylindrical in form to reduce to a minimum the swirling of the damping medium. One type goes to the extreme of having the bowl in the form of a sphere. However, if a sufficiently generous clearance is allowed between the card and the interior of the bowl, the error caused by swirling will be relatively small.

The damping medium, if a liquid, reduces shocks, partially eliminates the effects of friction and vibration, and reduces the weight of the rotating system on the bearing. Its primary function, whether or not it is a liquid, is to damp excessive oscillations of the rotating system. The degree of damping depends upon the viscosity of the damping medium as well as upon the construction of the moving parts. Hence, very low temperatures which cause a very considerable increase in the viscosity of liquids may be expected to make the compass more sluggish than usual in its operation. On the other hand, abnormally high atmospheric temperatures do not decrease the viscosity of the damping fluid sufficiently to cause any appreciable difference on the action of the compass.

In air-damped compasses the friction of the air on the moving parts provides the only damping influence outside of the pivot friction. It is obvious that in these compasses the surface exposed to the damping effect must be greater in area than that required for a compass damped by liquid.

Several liquids have been used for compass damping, but at present only colorless, acid-free kerosene or a mixture of alcohol and water are in general use. More than 30 percent of alcohol is undesirable because of its solvent effect upon practically all kinds of paint. It has been the almost universal practice to fill the aircraft compass with the distilled water and alcohol mixture.

To compensate for volumetric changes in the liquid, an expansion chamber composed of a thin metal diaphragm much like those used in aneroids is most frequently employed. In some cases a hollow chamber in the top of the bowl is used, into which excess liquid may flow when expansion takes place. This also acts as an air trap for bubbles.

To enable the pilot to make accurate observations of the headings of the aircraft, a reference line called the *lubber's line* is placed inside the bowl on the side from which observations are made. In mounting the compass, care should be exercised to insure that this lubber's line is parallel to the axis of the fuselage.

Modern compasses are fitted with an illuminating device for night flying. In some cases the light from a miniature electric lamp passes through a small pane of ground glass to prevent glare. Designs which do not permit the light to fall directly on the card should provide for illumination either by transparency of the card or by reflection from properly painted inner surface areas on the interior of the bowl.

A compass compensator is a device containing movable magnets which can be so arranged that they counteract the magnetic forces which cause deviation. There are several different types in use which accomplish the same purpose. Due to the limited space, small compensators are used on aircraft compasses. They form a part of the compass, being located on the compass case directly above or directly beneath the compass card. Provision is made for moving the magnets to create the compensating magnetic forces required for a particular compass installation. In building a compensator it is assumed that a magnetic force in any direction can be resolved into two components at right angles to each other; therefore two sets of magnets are provided in the compensator—one to create a compensating force along the fore-and-aft axis of the aircraft and another set to create a compensating force along the athwartship axis of the aircraft. No attempt is made in aircraft compass calibration to compensate for magnetism induced in soft iron or for heeling error.

Magnetic compasses are delicate instruments and should be handled with special care. They should always be kept in their boxes until required for use, and should never be subjected to shock. Before being installed in an aircraft a compass should be tested as follows:

1. *Pivot friction.*—Place the compass on a level surface, well away from magnetic disturbances, and allow it to settle, tapping gently once or twice; note the reading of the compass. Bring a corrector magnet near the compass and deflect the magnet system 5°; on the

removal of the deflecting magnet the magnet system should come to rest in its original position. If a small error is observed, it should disappear when the compass glass is tapped with the finger; if it cannot be eliminated in this way, the compass is unserviceable and should be returned to the makers.

2. *Discoloration.*—The paint in the compass bowl should be free from discoloration and the liquid free from sediment. A discolored compass should be watched for pivot friction.

3. *Compass liquid.*—The compass bowl should be completely full of the correct liquid. No bubble, however small, should exist, as the presence of a bubble greatly accentuates liquid swirl. In modern aircraft compasses the liquid is de-aerated before the compass is finally sealed, and expansion chambers are designed to cover a large temperature range. If a bubble forms, the compass is defective and should be returned to the makers.

4. *Movable parts.*—If a compass is fitted with a rotatable grid ring, this must be free to move easily, and the locking device should be tested for serviceability. If the compass is a bearing compass, the prism and sighting devices should be examined for possible damage.

5. *Excessive vibration.*—If the sponge rubber pads supporting the compass bowl have deteriorated or settled down, the vibration of the aircraft will be transmitted to the bowl and so to the magnet system, causing irregular movements of the system, and hence an apparently unstable compass. To test, move the compass bowl slightly in the fore-and-aft and athwartship directions and see that it does not come in contact with the container. If the antivibrational devices are in any way defective the compass should be returned to the makers.

No definite rules can be laid down for the distance of a compass from magnetic parts to insure minimum deviation, as the deviation depends upon the degree of magnetism which the parts have accidentally acquired. The following distances should, in general, be allowed between the compass and movable parts, if the latter are magnetic:

(*a*) Control column, 18 inches.

(*b*) Untwisted direct current wiring, 36 inches. If direct current wires are twisted over each other they have no effect. Alternating current wires have no effect.

(*c*) Essential removable parts, such as cranks and tool kits, 36 inches.

Doubling the distance of a part from a magnet decreases the effect of the part to approximately one-eighth of its previous value, since the force between two magnets varies inversely as the cube of the distance, although single magnetic poles obey the inverse square law.

Steel and iron are practically the only magnetic materials used in aircraft. Duralumin, aluminum, brass, bronze, and wood have no magnetic effect upon a compass.

Calibration of the Compass

The calibration of an aircraft compass installation consists of compensating to reduce the deviation to within practical working limits (0°–4°) and the checking of the compass on enough headings to furnish, with sufficient accuracy for navigational purposes, a knowledge of the residual deviation on any heading.

The most convenient method of doing this, when facilities are available, is by means of a magnetic compass rose correctly laid out on level ground to indicate magnetic headings at least every 30° from 0° to 360°: If a magnetic compass rose is not available one may be laid out by means of a good compass and some form of pelorus. The compass, when placed where it is unaffected by anything but the earth's magnetism, will indicate magnetic north, and the pelorus can be used for laying out the markings every 30°. A check should be made to insure that the compass is unaffected by any purely local magnetic force, such as might be caused by a buried piece of iron or submerged electrical conduit. This is accomplished by sighting at a distant object (at least 6 miles away) and trying the compass in two or three locations in the same general vicinity. If the magnetic bearing of the distant object remains the same, it is reasonably safe to assume that no detrimental local magnetic attraction exists.

Before undertaking the calibration, the compass installation should be inspected. The compass case should move freely in the self-centering bearings of the compass mount. Since the mount carrying these bearings is generally located on the back of the instrument panel in a relatively inaccessible position, the bearings are frequently neglected. Unsatisfactory compasses and mounts should be replaced as necessary.

The aircraft should be placed approximately over the center of the compass rose and leveled up in a normal flying attitude. Plumb bobs are dropped bow and stern from the fore-and-aft center line of the aircraft and are used in lining up the aircraft on various magnetic headings. It is unnecessary to keep the aircraft centered exactly over the compass rose when moving it from one heading to another, the same end being achieved if the fore-and-aft line of the aircraft is parallel to the line on the compass rose which indicates the desired magnetic heading. Tape measures can be used to determine when the forward plumb bob and the after plumb bob are the same distance from the desired line on the magnetic compass rose,

i. e., when the aircraft is parallel to the line and thus on the magnetic heading.

The aircraft should be inspected to insure that the compass is affected only by such magnetic forces as will be present during actual flight. All gear which will be carried in flight must be stowed in its proper place. All electrical and radio circuits should be energized to determine whether or not they affect the compass. Since deviation varies with the heading, this electrical check should be carried out on several headings. In some cases the position of the flight controls has been known to affect the compasses.

In order that any subsequent magnetization of parts may have a minimum effect during flight, the controls should be secured during calibration in the position they will occupy during normal flight. The engine should be running during compass calibration, as it will furnish sufficient vibration to eliminate errors which might be caused by a slightly sluggish compass pivot. It is also necessary to have the engine running in order to determine the effect of the generator current on the compass. In operating units, where the effect of the running engines has been determined, it is not customary or even necessary to have the engine in operation. The necessary vibration can be achieved by tapping the compass, and with proper shielding the generator currents will not affect the compass. Aircraft having retractable landing gear containing movable parts within 3 feet of the compass should be tested to insure that this gear does not affect the compass. This can be done by hoisting the aircraft, then raising and lowering the landing gear on several headings. If the compass does not read the same with the landing gear retracted as when the landing gear is down, handling trucks must be provided and the compasses calibrated with the landing gear retracted.

In cases where it is found that electrical circuits affect the compass and the fault cannot be corrected, the navigator must decide what circuits will be kept energized during calibration, bearing in mind that flight conditions must be simulated as closely as possible. When lighting circuits affect the compasses it is necessary to make two deviation tables, one for day use and one for night flying. When flight conditions have been simulated as closely as possible, the calibration is carried out in the following manner:

1. Place aircraft on a magnetic heading of 090°.

2. Set N-S compensator screw to zero reference mark, using a nonmagnetic screw driver. Adjust E-W screw until compass reads 090°.

3. Head aircraft 180° magnetic. Adjust N-S screw until compass reads 180°.

4. Head aircraft 270° magnetic. Note deviation and reduce one-half by adjusting E-W screw.

5. Head aircraft 000° magnetic. Note deviation and reduce one-half by adjusting N-S screw.

6. Successively place the aircraft on each 15° heading from 0° to 360°, and record compass readings on compass-correction card as shown below.

NOTE.—It has been determined that compensation for every 30° heading is sufficiently accurate for normal operations.

Compass No. —— Plane No. - Date - Lat. ——

Magnetic heading	0	15	30	45	60	75	90	105	120	135	150	165
Compass heading	2	17	33	48	64	78	93	107	122	136	150	164
Magnetic heading	180	195	210	225	240	255	270	285	300	315	330	345
Compass heading	179	194	208	222	237	252	267	283	299	315	330	346

FIGURE 25.—Correction card, aircraft compass.

When the compass-correction card has been filled out as shown above, it is posted in the cockpit in the vicinity of the compass, where it can be easily seen. The pilot can now readily determine what compass heading to steer for a certain magnetic heading. The card takes place of a deviation table. Suppose the pilot has worked his navigation and determined his required magnetic heading to be 210°. Glancing at his compass-correction card he sees that he has to steer a compass heading of 208°.

If his magnetic heading is some figure that is not given on the card, he interpolates between the two values given.

The problems listed below may be solved by the student using the compass-correction card in figure 25 for deviation corrections:

Compass heading	Magnetic heading	Variation	True heading
060	056	13 E.	069
067	063	1 W.	062
024	021	18 W.	003
148	---	10 E.	---
221	---	5 W.	---
---	---	3 E.	231
---	---	21 W.	149
000	---	------	021
231	---	15 E.	249
---	179	16 E.	---
---	322	10 W.	312
---	246	----	257

Excessive deviation.—In some types of aircraft it will be found that many of the larger structural parts in the vicinity of the compass are highly magnetized. In cases of this kind the compensating magnets of the compass are not effective and the magnetism of the parts will have to be neutralized.

Northerly turning error.—A bar magnet or dip needle free to move about a horizontal axis, that is in a vertical plane, will align itself

parallel to the magnetic lines of force of the earth's field. The magnetic equator is the line passing through the various points on the earth's surface at which the dip needle is 0° or lies horizontal. As the dip needle is carried north or south from the magnetic equator it dips toward the nearer magnetic pole. The inclination or angle of dip increases with the magnetic latitude, until at the earth's magnetic poles, the dip needle is vertical or 90°.

The compass, when the aircraft is in level flight, is free to rotate about a vertical axis, and its directive force is the horizontal component of the earth's magnetic force. The vertical or dip component of the earth's magnetic force attracts the north end of the compass and tends to depress it. However, a small mass on the south side of the compass card tends to offset this dip effect. Suppose the aircraft is heading north and makes a turn to the east or right. When the aircraft is banked to the right the compass is tilted by centrifugal force with its east side down and the north end will be attracted downward or to the east by the dip component. The axis is no longer vertical so the card is free to rotate to the east. This rotation will cause the compass to indicate a left turn. The turning of the aircraft from north to east will cause the compass to indicate a right turn. So it is seen that the two forces tending to rotate the compass are acting in opposition. If the aircraft is not banked too steeply the force of turning will be greater than the force of rotation due to the dip component. The result will be that the compass will indicate a right turn, but the turn indicated will be slower and of lesser amount that the one actually made. If the aircraft is banked sharply enough the force of rotation due to the dip component will be greater than the force of turning and the compass will indicate a left turn although a right turn is actually being made. This left turn will be indicated only at the beginning of the turn, then the compass will indicate a right turn. In turning from north to west the turn is left. The west side of the card is down in this case and the dip component will cause the north end of the compass to be deflected to the westward, indicating a right turn. Again the two forces are in opposition.

From the above it is seen that when on a northerly course and a turn is made away from north the compass will indicate a slower turn of lesser amount than is actually being made, and, in some cases where the bank is steep enough, may even indicate an opposite turn for a limited time.

Flying on a southerly course and turning away from south the two forces will act in conjunction and the result will be the compass will indicate a greater and faster turn than is actually being made.

Flying on an easterly or westerly course, making a turn the effect of the dip component is negligible.

The error as described above is dependent upon the angle of bank and the duration of the turn. Because the effect is greatest when turning toward the east or west away from north it is termed "*Northerly Turning Error.*"

In clear weather the "Northerly Turning Error" is of minor importance, but it is obvious that pilots flying a northerly course in fog or thick weather, and whose aircraft are turned by gusts or bumpy air, may, in attempting to return to the desired course, only increase the turn and, unless warned by some other indication, eventually find themselves in spins. It has been proven that some of the pilots who were lost while attempting transoceanic flights encountered disaster through ignorance, or lack of experience of this condition. Pilots formerly were cautioned to avoid, if possible, flying on northerly courses when poor visibility conditions were encountered. At present the Directional Gyro, and the Turn Indicator, to be discussed later, are used in making turns.

Other types of compasses that are in use should be mentioned here.

Aperiodic compass.—This is a magnetic compass that has no period. In other words after being displaced from its equilibrium position, it returns by one direct movement to the north-pointing position, instead of executing a series of oscillations. The aperiodic compass has no card, but the degree marks are shown on a rotatable verge ring that carries a set of parallel grid lines running in the north and south direction. The verge ring is set for the desired course and the pilot then steers this course by keeping the grid lines parallel to the long north and south pointers of the needle system. The greatest disadvantage of the aperiodic compass is that it must be mounted below the level of the pilot's eye to be read.

Earth inductor compass.—This type is also a magnetic compass, but differs in the fact that magnetized needles are not employed to detect the earth's field. Instead, a coil of wire, the plane of which is vertical, is rotated about a vertical axis. The two ends of the coil terminate in diametrically opposite segments of a simple commutator. When the plane of the rotating coil is parallel to the lines of force of the earth's magnetism a maximum difference of potential is induced between the coil's two commutator segments, and a large deflection of the galvanometer occurs. When the plane of the rotating coil is at 90° to the lines of force no current is set up, because no potential is induced, and the galvanometer indicates zero. The rotating coil is set on a scale for the desired heading and when the aircraft is placed on this heading the plane of the coil is perpendicular to the lines of force of the earth's magnetism and the indication of the galvanometer is zero. The pilot now flies so as to maintain this zero deflection. When changing to another heading the rotating

coil is set for the new heading and the aircraft turned until zero deflection is again attained.

Sun compass.—This type of instrument which is in no way magnetic, is used for very high latitudes where the magnetic compass is sometimes uncertain. The principle of the sundial is utilized. The shadow pin is set in a position approximately parallel to the earth's axis, and the compass dial is set to local apparent time. The shadow now cast by the shadow pin indicates the heading of the aircraft on a card. To use this special type of direction finder it is necessary that, (1) the sun be always shining, (2) the latitude be known for setting the shadow pin, and (3) the longitude be known to set the compass dial to local apparent time. The sun compass is impracticable for conditions other than in the polar regions.

Gyroscopic compass.—Because of the weight necessary and the fast movement of the aircraft together with other difficulties a gyroscopic compass suitable for aircraft has not been developed. However an instrument combining the features of the gyroscope and the magnetic compass, known as the gyro magnetic compass, has been developed and will be discussed later under new developments.

Gyroscopic Instruments

Before proceeding with a description of the gyroscopic instruments a brief discussion of the gyroscope and its characteristics is given.

The gyroscope is a flywheel, so mounted that only one point—its center of gravity—is in a fixed position, the wheel being free to turn in any direction around this point. It has three angular degrees of freedom.

Referring to figure 26 the wheel, or rotor (1) revolves in bearings (2) in a concentric, inner ring (3). This ring is free to revolve in pivot bearings in an outer ring (4) about an axis (5) which is always at right angles to the axis of rotation of the wheel. The outer ring, likewise, is free to revolve in pivot bearings in a supporting frame (6) about an axis (7) which is always at right angles to the axis of rotation of the inner ring. With a universal mounting such as this, the axle of the wheel may be pointed in any direction by a touch of the finger.

All practical applications of the gyroscope are based upon two fundamental characteristics, namely: "Rigidity" and "Precession."

Consider for a moment only the rotor of the gyroscope and the axle about which it spins. With the rotor spinning at required speed the axle will remain pointed in whatever position it is set, unless disturbed by some external force. This characteristic is known as "Rigidity."

When a gyroscope is subjected to a couple or force about an axis at right angles to its axis of rotation (as axis 5) it resists that couple, and instead of turning about that axis it will turn or precess about a third axis (as axis 7) which is called the axis of precession. The degree of resistance is proportional to the velocity with which the gyro turns, or precesses, about the axis of precession (axis 7).

A convenient way to remember the direction of precession is to regard the applied couple as a push acting at a single point on the rim of the wheel. This point will not move in response to the push,

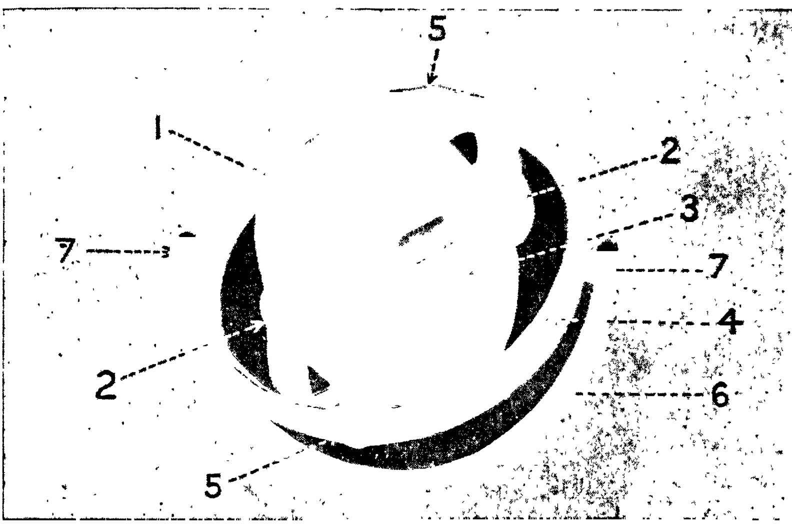

FIGURE 26.—Gyroscope.

but a point 90° beyond, in the direction of the wheel's rotation, will move away instead.

The turn and bank indicator.—The turn indicator and the bank indicator are separate and distinct instruments.

The *turn indicator* is dependent upon the gyroscopic principle of "precession" for its action. Referring to figure 28 the rotor *G* rotates at very high speed (about 10,000 r. p. m.), being driven by the stream of air from the jet *J*. Air is sucked out of the case at point *N* as will be discussed later, and entering air is directed through the jet *J* against the rotor. Its axis is carried in the frame *F* which is mounted on pivots front and rear so that the frame can rotate as

shown by the arrow at Q. A round disk or plate P is mounted on the frame, with a spring fastened at the top which tends to prevent rotation of the plate and keep the part marked T at the top. The pin S at the bottom of the plate rides between the prongs of a fork R in such a way that the hand rotates in the opposite direction to the plate. As an illustration, when the aircraft is turned to the right, it causes the instrument to be rotated to the right about a vertical axis. The gyro tries to carry its frame around so that the gyro axis will also be vertical. The motion, in the direction of the arrow Q, if completed, would leave the gyro rotating in the same way that the aircraft is turning. The spring is stretched until the force exerted by

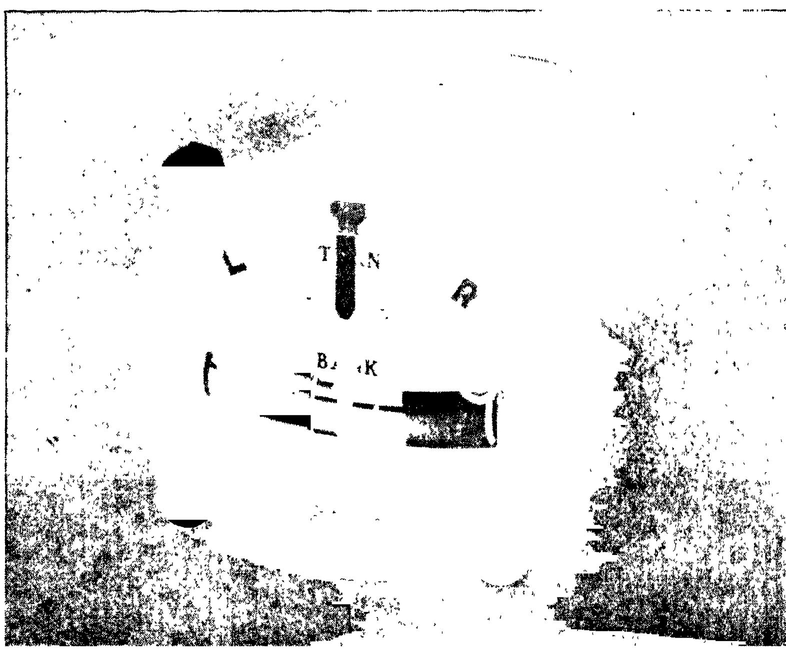

FIGURE 27.—The turn and bank indicator.

it and that of precession of the gyro are equal. The hand will be drawn over until this condition is reached, and will remain in this position as long as the aircraft continues to make a constant turn. When the turn is stopped there is no longer a force of precession, and therefore the spring will return the hand to the central position. The force of precession is of course dependent upon the rate of turn of the aircraft, hence the amount of deflection of the hand affords a measure of the rate at which the aircraft is turning. The amount of deflection of the hand is governed by the tension of the spring, and by adjusting the spring the deflection may be set for a certain rate of turn. Figure 27 shows the hand centered. The *bank indicator* consists of a

steel ball free to roll in a curved glass tube as shown in figure 27. The glass tube is filled with liquid to dampen the motion of the ball and prevent rapid oscillations. The tube is mounted in the aircraft

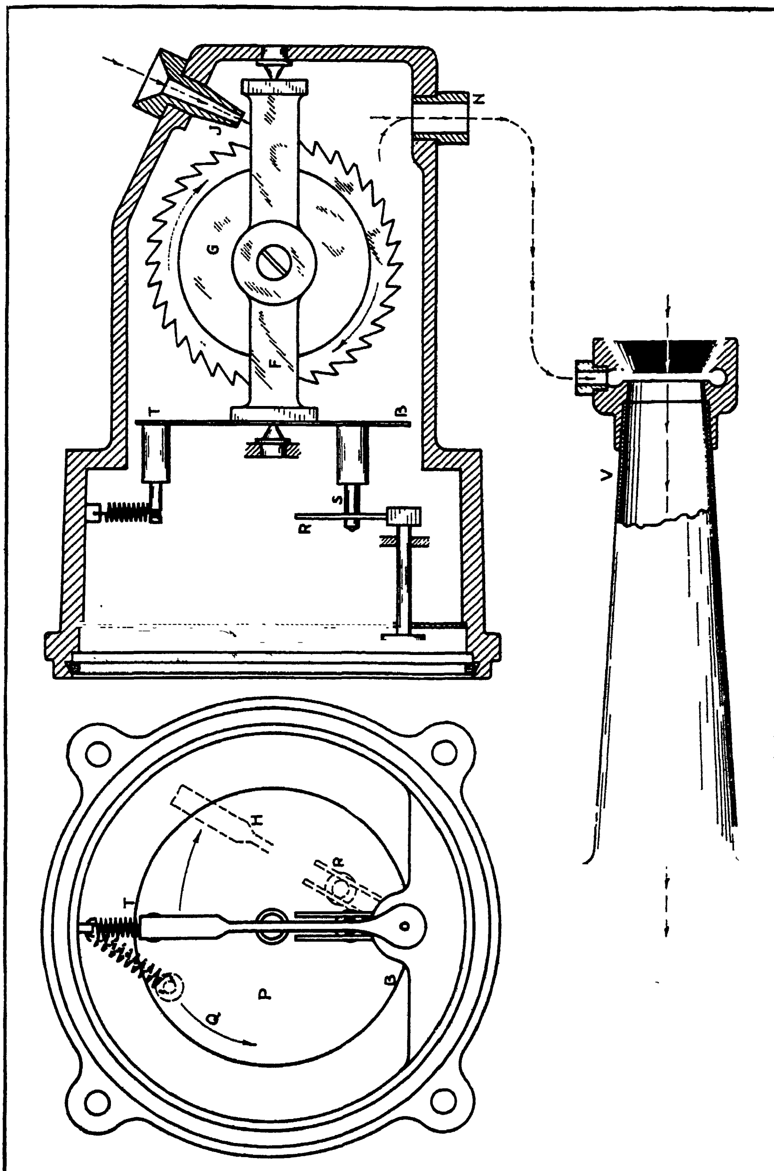

FIGURE 28.—Schematic diagram of a turn and bank indicator.

so that the center is the lowest part of the tube. When the aircraft is in level flight the ball will be acted upon by gravity alone and will come to rest at the center of the tube. During a turn, centrifugal

force tends to roll the ball toward the outside of the turn, whereas gravity tends to roll it toward the inside of the turn because that will then be the lowest part of the tube. In a correct turn the resultant of these two forces is through the center of the tube, thus causing the ball to remain in the center. It is seen that the bank indicator does not indicate the amount of bank, but does indicate whether one wing is lower than it should be. If a turn is being made with too much bank the ball will be actuated to a greater extent by gravity than centrifugal force and will show the inside wing to be too far down. This is corrected by raising that wing by use of the ailerons. On the other hand if too much rudder is used in turning, the ball will be rolled to the outside by centrifugal force. This may be corrected by again using the ailerons to roll the ball to the center. In other words increase the bank to the correct amount for the turn being made. Above it was recommended that the ailerons be used for centering the ball in turns. The reason is, that in instrument flying the rate of turn is the dominating factor. This can be regulated easily by use of the turn indicator and all that remains is to center the ball with the ailerons.

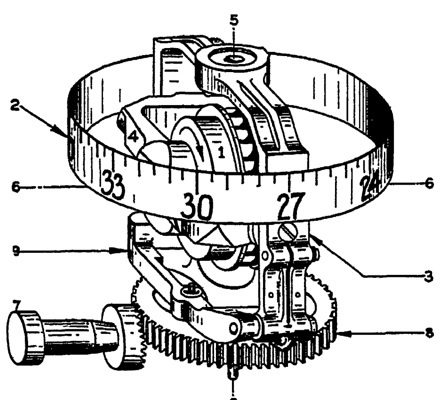

FIGURE 29.—Principal parts of the directional gyro.

The directional gyro.—The directional gyro consists of a small rotor (1) as shown in figure 29, spun at very high speed (about 10,000 r. p. m.), and a circular card (2) graduated in degrees, attached to the vertical ring (3), in which the rotor and its gimbal ring (4) are mounted. The vertical ring and card are free to turn in azimuth in the vertical bearings (5) and a rectangular opening in the front of the instrument case permits a view of an ample sector of the card. The gyro axle (6) is horizontal in normal operations.

The directional gyro makes use of the gyroscopic principle of rigidity for its operations. Thus, the rotor, its supporting ring, and the card, which is attached to the vertical ring, remain fixed in azimuth no matter how much the aircraft yaws or turns. Unlike the compass the directional gyro has no directive force to return it to a fixed heading. It is therefore set while in level flight to the indication of the magnetic compass. One error of the instrument is caused by its tendency to creep. This has been reduced to the point

where it will remain within 3° of the original setting for at least 15 minutes. Therefore about every 15 minutes the instrument must be checked and reset if necessary by means of the caging knob (7), underneath the dial. When the caging knob is pushed in, it engages the azimuth gear (8), to permit the setting of the card, and at the same time raises the caging arm (9), which brings the gyro axle horizontal and holds it in that position.

The directional gyro is limited to 55 degrees displacement in climb, glide, or bank and any turns in which the instrument is to be used should be held within this limit. If the limit stops are reached the instrument will precess, and give false indications; in this case it should be caged and reset before using again.

The directional gyro is used to obtain directional control and is read in the same manner as the compass. Much more accurate control is possible due to the fact that the directional gyro does not swing or oscillate, and therefore provides as positive a reference for steering as objects along a clear natural horizon. The instrument must be originally set to the magnetic compass reading and reset at intervals of about 15 minutes to compensate for the creep of the gyro. Care should be taken when setting or resetting the directional gyro, especially in rough air, to be certain that a correct compass reading is obtained. It must be remembered that in rough air the magnetic compass will swing to a certain extent and when the card appears to be stationary it may actually be at the end of a swing and therefore, will not indicate the true magnetic azimuth. To avoid this trouble the aircraft should be held as straight as possible for about a minute by a directional gyro setting approximately the same as the compass reading, during which time the compass may be observed to determine its average reading during swings, and the directional gyro then properly set. When uncaging the gyro after setting, the caging knob should be pulled straight out.

A corrective feature is included in the directional gyro to keep the rotor in an upright position. This is accomplished by dividing the entering air into two parallel jets, with each jet striking the buckets in the rim of the gyro at points equidistant from the center. If the rotor tilts, the air from the jet on one side strikes against the rim instead of the buckets, while air from the other jet strikes the side of the buckets, causing the rotor to return to its upright position.

The Gyro Horizon.—The gyro horizon makes use of the gyroscopic principle of rigidity. It derives its indication from a gyro spinning in a horizontal plane about a vertical axis Z as shown in figure 30. The mechanism of the instrument in the case is pivoted about the longitudinal or rolling axis X. The gyro is contained in the housing (1) which is carried on a pivot in the gimbal ring (4) so as to be free to turn about the athwartships or pitching axis Y. The horizon

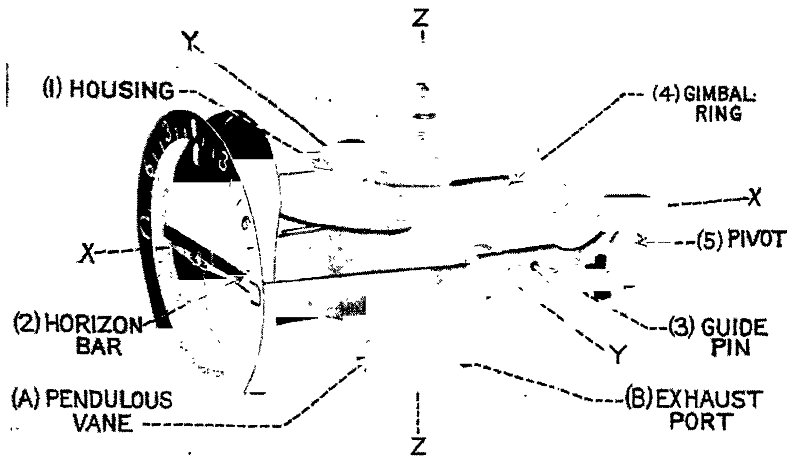

FIGURE 30.—Principal parts of gyro horizon.

bar (2) is carried on an arm pivoted at the rear (5) of the gimbal ring and is controlled by the gyro through the guide pin (3). When the aircraft noses up as in figure 31 the plane of the gyro remains

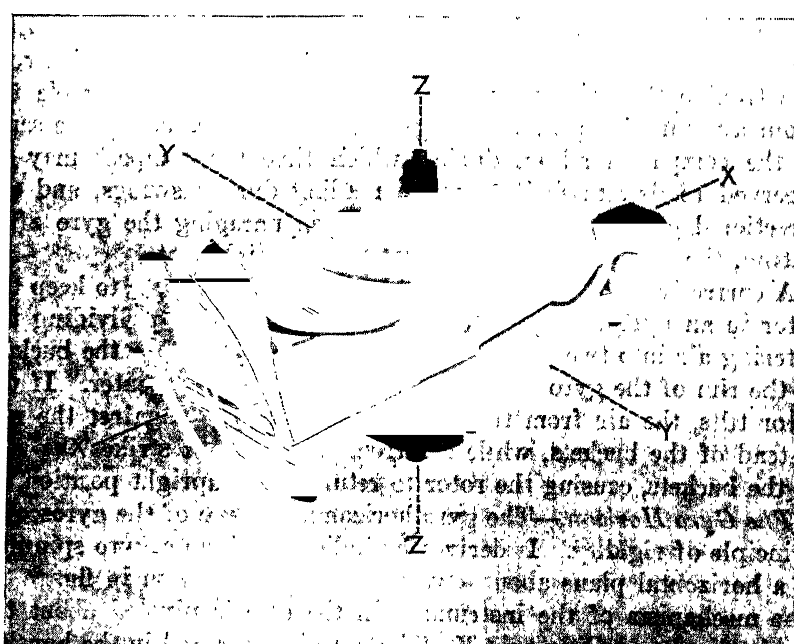

FIGURE 31.—Gyro horizon mechanism in climb.

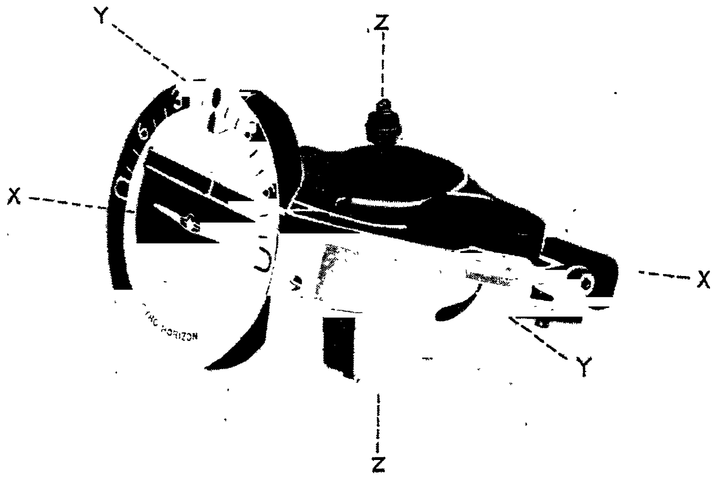

FIGURE 32.—Gyro horizon mechanism in glide.

horizontal, causing the horizon bar to go down through its connection at the guide pin. Thus the miniature reference airplane in the instrument is above the bar, showing a nose high condition. Reverse

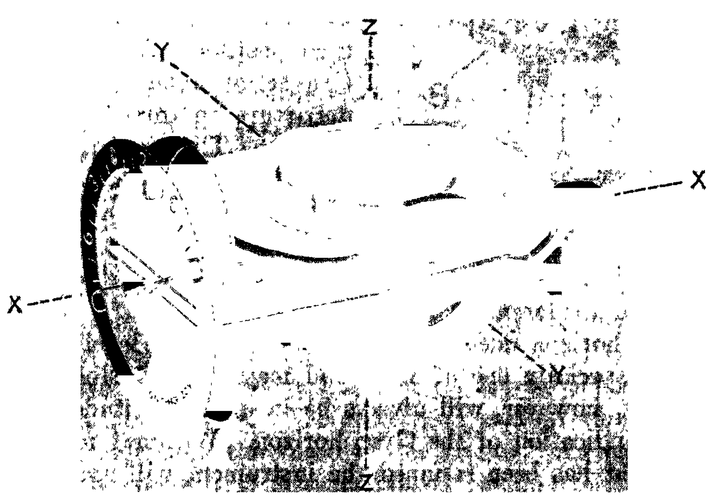

FIGURE 33.—Gyro horizon mechanism in bank.

action takes place as shown in figure 32 in the case of a nose down condition. When the aircraft banks, only the instrument case and the miniature airplane are carried with it, while the mechanism of the gyro wheel, gimbal, and horizon bar remain level as shown in figure 33.

The air that spins the gyro is exhausted in four horizontal jets through four openings, one of which is shown at B in figure 34, spaced equidistant at the bottom of the gyro case. Pendulous vanes, one shown at A, extend down over these openings, and when the gyro axle is vertical, each covers half of its corresponding opening. If the gyro axle inclines from the vertical, one of the vanes covers more than half of its opening, and the vane on the opposite side covers less than half. The air jet is thus increased on the side of the greater opening and the effect is similar to a gentle pressure exerted on the bottom of the casing in a direction opposite to the flow of air. Impelled by this slight force, the gyro obeys its second fundamental principle, precesses at right angles to the applied force, and moves back to the vertical position. A similar corrective action takes place for any departure in direction from the vertical. The righting action of the precessional forces is such that the gyro axle is never permitted to depart more than 1° or 2° from the true vertical, and for all practical purposes the artificial horizon bar is as good a reference as the natural horizon.

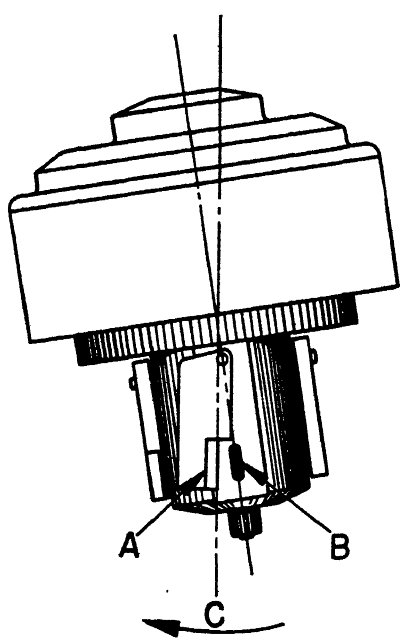

FIGURE 34.—Erecting action of the pendulus vanes of the gyro horizon.

The gyro horizon does not indicate the absolute level at the end of a turn, especially one of 180°, and may be off a slight amount. The aircraft, however, will always be in a safe attitude if leveled out by the indication of the Gyro horizon. Within 1 minute after straight flight has been resumed the instrument will again be indicating correctly.

The gyro horizon allows 60 degrees climb or glide and 90 degrees bank before the limit stops are reached. These limits should not be exceeded, particularly when flying by instruments. Should the stops be reached the gyro will precess out of the vertical, rendering

the indications valueless. In this case a short time should be allowed for the instrument to erect itself.

The gyro horizon is used as a basic reference for lateral and longitudinal control of the aircraft. The horizon bar in the instrument remains parallel to the natural horizon while the miniature airplane is fixed to the case and remains parallel to the athwartships axis of the aircraft. Lateral control is, therefore, accomplished by flying the aircraft so as to keep the miniature airplane parallel to the horizon bar. For longitudinal control the horizon bar is connected to the gyro in such a manner as to cause the bar to take a position relative to the miniature airplane equivalent to the position of the aircraft to the natural horizon. Thus longitudinal control is similar to lateral control in that control is applied to keep the miniature airplane on the horizon bar in the same manner that the nose of the aircraft is held on the natural horizon.

For use in military or other aircraft which are called upon for considerable maneuvering or acrobatics, a gyro horizon with a caging device should be used. The caging device affords a means of quickly regaining the use of the instrument at the conclusion of rolls, loops, or other maneuvers.

Pumps and venturi tubes.—The gyroscopic instruments just described may be operated by either venturi tubes or by a vacuum pump. In either case air is drawn out of the case of each of the instruments. This forms a partial vacuum and air entering the case to take the place of that drawn out is directed through a nozzle and against the buckets on the rim of the rotor. The speed at which the rotor is turned is therefore dependent upon the amount of vacuum in the case of the instrument. A vacuum relief valve as shown in figure 35 is used to hold the vacuum supply to the value best suited to the operation of the instrument.

The venturi tube is so designed that when air is forced through the tube a suction will be created in the throat or smallest part of the tube. The amount of this suction is approximately proportional to the square of the air speed of the aircraft. A venturi tube is necessary for each instrument.

The vacuum pump is recommended if the engine is equipped with the necessary pump drive. The amount of suction afforded by the pump is dependent on the speed of the engine. An engine-driven pump may operate several instruments.

Figure 35 shows a connecting diagram for single engine aircraft. Here both venturi tubes and a vacuum pump are installed. In case of pump failure the selector valve is turned and the venturi tubes will operate the instruments. On multi-engine aircraft it is common practice to install two vacuum pumps connected to a selector valve.

The gyropilot.—The *gyropilot* may be likened to the human body, acting on the controls of an aircraft through its "Brain," "Nerve," and "Muscular" system in much the same manner as does the human pilot.

The *control gyros* are the "Brains"; the *servo unit* the "Muscle"; and, the *air relays* and *oil valves* are the "Nerve" system that ties the "Brain" and "Muscle" together in order to obtain controlled action. The follow-up mechanism is also part of the "Nerve" system, carrying information back to the "Brain" from the "Muscle." The action of the follow-up is such that control is applied in proportion to disturbance, and overcontrolling of the aircraft is, therefore, prevented.

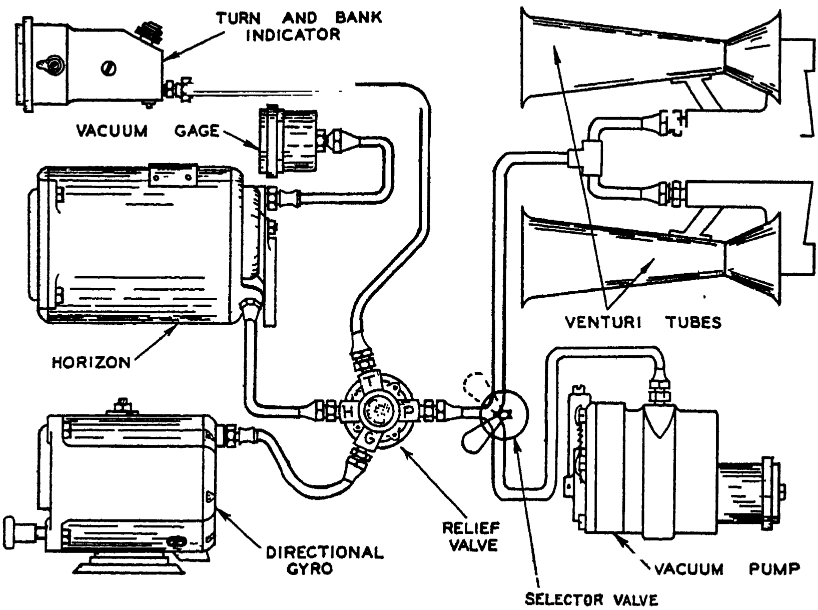

FIGURE 35.—Connecting diagram.

The directional gyro and gyro horizon are the two main units that form the "Brain" of the gyropilot. Around the gyros are the air pick-offs (X-X^1) as shown in figure 36.

NOTE.—There are three sets of air pick-offs—two connected with the bank-and-climb gyro for lateral and longitudinal control, and one with the directional gyro for directional control.

To illustrate the action of the gyropilot, only the aileron control will be used. (The rudder and elevator controls are operated in a similar manner.)

In figure 36 the attitude of the aircraft laterally is normal. In the air pick-off (X-X^1) are two ports (D-D^1). In this position,

air from the air relays flows equally through the ports as indicated by the arrows (D-D^1).

When the aircraft deviates from level flight laterally as exaggerated in figure 37, the air pick-offs, which form an integral part of the aircraft, take up the position as shown. Port D^1 is shut off and port D is opened. Air, therefore, flows through port D and actuates the air relay-operated oil valve which transmits oil to the servo piston to move the ailerons in the correct direction to bring

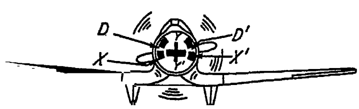

Figure 36

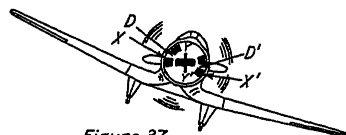

Figure 37

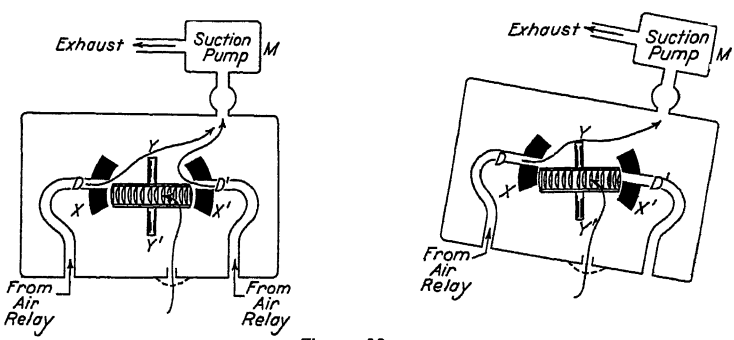

Figure 38

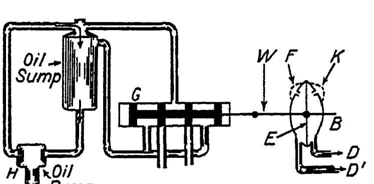

Figure 39

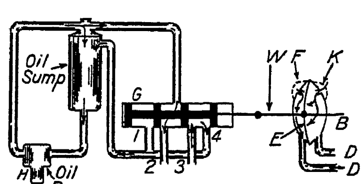

Figure 40

Schematic illustrations of the gyropilot.

the aircraft horizontal. The operation is reversed if the aircaft takes the opposite direction.

Figure 38 shows the gyro and the aileron air pick-offs placed in a box. Air is drawn into the bottom of the box by the suction pump M and directed to the gyro to spin it. Air is also drawn in from the air relay (through ports D and D^1 when the aircraft is level) by the suction pump and exhausted at the top. With the aircraft in

the position as shown in figure 37, the box is tilted and air is drawn through the port D only, as shown in figure 38 at the right, port D^1 being closed.

The *nerve system*, consisting of the air relay B, and the balanced oil valve G, is shown in figure 39. E is the diaphragm and F and K are two inlet ports which are smaller than the exhaust openings to the air pick-offs at the bottom of the relay.

G is the balanced oil valve which is connected to the air relay by the piston rod W. In figure 39 the system is neutral, the aircraft being level as in figure 36. Therefore, air is being drawn equally from the exhaust ports and entering through ports F and K, maintaining equal suction on both sides of the diaphragm. There is no deflection of the diaphragm E, the oil valve piston is in the position shown, and no oil is permitted to flow to the servo cylinder.

If the aircraft changes attitude laterally one of the ports (D-D^1) of the air pick-off is opened fully and the other closed. This causes one side of the diaphragm in the air relay to receive the increased suction while the suction on the other side falls off, since it is shut off at the air pick-off and outside air can still flow in at K. Figure 40 shows the operation of the nerve system when there is suction at D^1.

The action of the diaphragm E moves the balanced oil valve to the left, permitting oil to flow to the servo unit through pipe 2. Oil from the other side of the piston returns through pipe 3 and flows back to the sump through pipe 4.

The *muscular system* consists of three hydraulic servo cylinders, one of which is shown in figure 41. Oil enters one end of the cylinder and moves the piston, an equal amount of oil being exhausted from the other side of the piston and returned to the sump. The piston rod (V-V^1) is connected to one set of the control cables of the aircraft.

When the human pilot is flying the aircraft manually, the valve R, figure 42, is opened, permitting the oil to flow through the by-pass tube and allowing the controls to be moved freely.

The three systems having been explained separately, figure 43 shows them combined. O is the suction regulator which keeps the vacuum at 4″ Hg., regardless of the speed of the suction pump, which varies with the speed of the motor. The oil sump, N, carries the reserve oil. Q is a valve which regulates the oil pressure from the pump and permits it to circulate through the sump whenever the balanced oil valve cuts off circulation to the servo unit. The servo relief valves, one of which is shown at P, permit the human pilot to overpower the gyropilot when the system is in operation. The speed-control valves, one of which is shown at Z, regulate the

speed of oil flow to the servo pistons and therefore control the speed with which the gyropilot operates the controls.

The final part of the nerve system has been added in figure 43—the follow-up system. It must be remembered in controlling an aircraft that it is not only necessary to apply control to bring the aircraft back to level when it has been disturbed, but also to begin to remove the applied control as the aircraft is returning to level, so that the control surface will be back in neutral when the disturbance has been fully corrected. A further requirement is that the

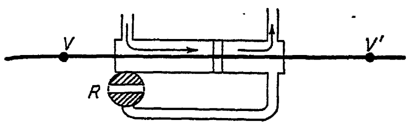

Figure 41

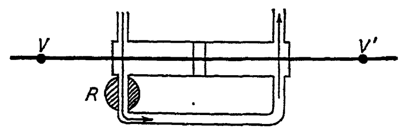

Figure 42

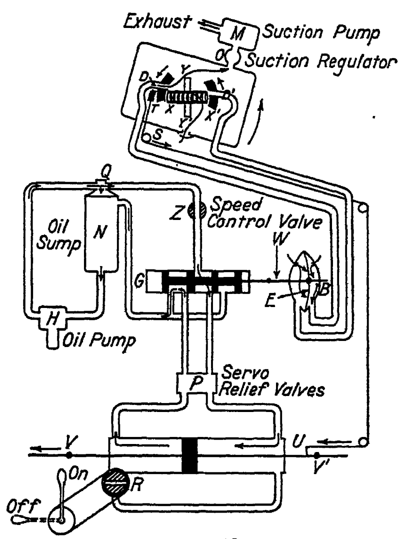

FIGURE 43
Schematic illustrations of the gyropilot.

amount of control applied be in proportion to the displacement of the aircraft. All this is necessary to both manual and automatic control and in the latter is handled by the follow-up. The air pick-offs X-X^1 are not fixed rigidly to the gyro box and the aircraft but, instead, can be moved in relation to them by the follow-up mechanism. A cable is connected to the servo piston rod at U and runs to the follow-up pulley S on the gyro box. The pulley controls a gear T which is connected to a gear on the air pick-offs X-X^1, which are commonly connected. When the piston V-V^1 moves to the left, the

follow-up cable at *U* moves likewise and gear *T*, through the action of pulley *S*, moves *X* down and X^1 up. When they reach a neutral position (both half open) the air relay and oil valve are centered and servo piston movement away from neutral is stopped. Now consider that the control surface movement which the servo has been producing has been bringing the aircraft back to level flight. As the aircraft approaches a level attitude, the air pick-offs which have been driven ahead of the gyro box pass beyond the neutral point and begin to cause servo movement in the opposite direction. This is not opposite control, but is the removal of the control originally applied. The mechanism and its ratios are so arranged that the correct amount of control will be applied and also removed at the proper rate as the aircraft returns to level.

Prior to take-off the gyropilot should be given a ground check as set forth in the instructions issued by the manufacturer. The primary reason for this is that all the air should be worked out of the system. Also a gyropilot which does not check out properly on the ground cannot be expected to perform satisfactorily in the air.

Directional control in the gyropilot is based on the directional gyro, which must be set with the magnetic compass and rechecked at periodic intervals. The average drift of a directional gyro should not be more than 3° in 15 minutes. A drift of 5° in 15 minutes is permissible on one heading, providing the average of the four cardinal headings does not exceed 3° in 15 minutes. When the aircraft is only 2° or 3° off the desired heading by magnetic compass, a small adjustment of the rudder knob, as shown in figure 44, will suffice to correct the heading. When there is an appreciable difference in reading between the compass and directional gyro, the gyropilot should be disengaged for a moment while the directional gyro is being reset.

Lateral control in the gyropilot is taken from the bank and climb gyro. The aileron knob can be set for either level flight or to any angle of bank up to 30° for use in either a fully automatic turn (using turn control) or in a turn where the turning is controlled by continued manual operation of the rudder knob.

Basic longitudinal control is taken from the bank and climb gyro. The desired longitudinal attitude is set by means of the elevator knob. Use of the level knob permits automatic control of altitude. To use the level control, first set the elevator knob to bring the aircraft's climb indicator to zero. Then turn the level knob slowly from OFF to LEVEL. This may cause some rotation of the elevator knob and a slight change in altitude, but when this ceases the aircraft will be stabilized at a practically constant pressure altitude within normal operating limits.

Turn the level knob to OFF position when it is desired to change altitude, then to ON when desired to stabilize at the new altitude.

In addition to straight flight which may be either level, climbing, or descending, the only maneuvers that a gyropilot should be required to perform are turns and spirals. Course changes of a few degrees may be made as flat turns, in which case it is only necessary to rotate the rudder knob slowly until the aircraft reaches the new heading. When automatic turn control is used, the turn control handle is moved to right or left (depending on the direction of turn desired) causing a small air motor in the directional gyro unit to drive the rudder knob and follow-up card in the proper direction to produce the turn. As the turn starts, the aileron knob should be turned to

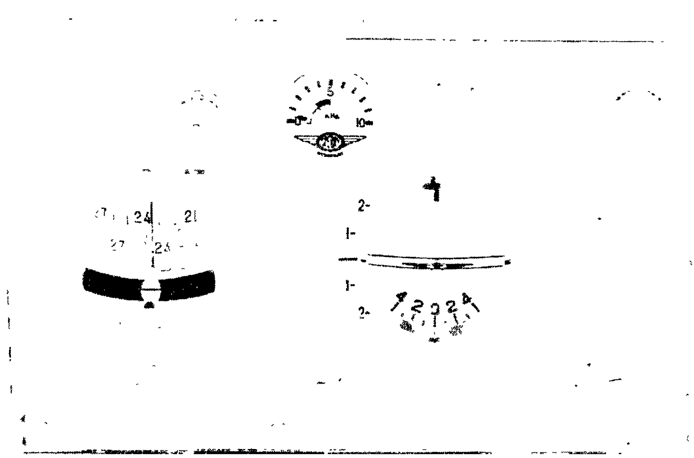

FIGURE 44.—Photograph of instrument board of Sperry automatic pilot.

produce the proper bank. As the desired new heading is approached, the turn control should be returned to zero and the aircraft leveled out by means of the aileron knob. After the turn control has been set to OFF it will be noticed that the aircraft will continue to turn at a decreasing rate and the directional gyro and rudder follow-up cards will continue to travel together. This is necessary to accomplish removal of the rudder control which was applied to create the turn. If the cards are still moving at a noticeable rate as the aircraft approaches the desired directional gyro heading for straight flight, set turn control for opposite turn, which will speed up neutralization of rudder. For control in a spiral the required climb or descent setting is made in conjunction with the turn setting in the same manner as in straight flight.

Changes in flight attitude, power, altitude and load shifts will affect the fore and aft trim of the aircraft and cause the gyropilot to hold the elevator against the out-of-trim condition. This may result in an oscillation of the elevator control. The trim of the aircraft can be checked by disengaging the gyropilot for a few seconds and noting whether the aircraft tends to nose up or down. A trim correction should then be made with the elevator trimming tab or stabilizer.

On aircraft equipped with individual by-pass valves for each servo, only the elevator control need be turned off to check trim. When by-passing a single servo cylinder, close the speed control valve to that control so that oil pressure to the other two controls will not be by-passed. In rare cases better control may result with a slight loading of the elevator control in one direction. In order that the human pilot will not have to suddenly apply a large force to the elevator to hold the aircraft when the gyropilot is disengaged, the aircraft should be kept approximately in trim during gyropilot operation.

When it is desired to resume manual control it is only necessary to move the engaging lever to the OFF position and take over the controls. As an added safety measure, servo relief valves are provided which allow for immediate emergency overpowering of the gyropilot by applying about twice normal force on the controls.

Recent Developments in Instruments

Absolute altimeter.—This instrument gives the pilot his exact altitude above the point on the ground directly below the aircraft. Referring to figure 45 it is seen that the instrument consists of a radio transmitter *A*, transmitting antenna *E*, receiving antenna *F*, radio receiver *D*, interference measuring device *C*, and an indicator *B*. A radio signal leaves the transmitting antenna *E*. It is picked up by the receiving antenna *F* after travelling the short distance between *E* and *F*, designated by *K*. The signal also travels down along path *G*, strikes the ground at *J* and is reflected back along path *H*. It is picked up by the receiving antenna *F*. The same signal has thus been received twice, but because the signal striking the ground follows a longer path it will be received later than the direct signal. This time difference will cause interference, and the amount of this interference is proportional to the distance above the ground. The interference is measured by *C* and is indicated at *B* in feet.

The instrument will measure height up to 5,000 feet above the ground. At present it weighs about 50 pounds, but this will probably have to be reduced considerably before it will be regularly accepted.

Gyromagnetic compass.—The directional gyro has the primary defect of erratic drifts in reading. It was proposed to hold the rotor assembly fixed with respect to the magnetic meridian by means of a suitable torque controlled by a pivoted magnetic element. The result of this is the gyromagnetic compass as shown in figure 46.

The rotor is mounted in an airtight housing fitted with an air inlet for driving the rotor, and four exhaust ports. A two-pivot magnetic element is mounted outside of the housing. Two cases are

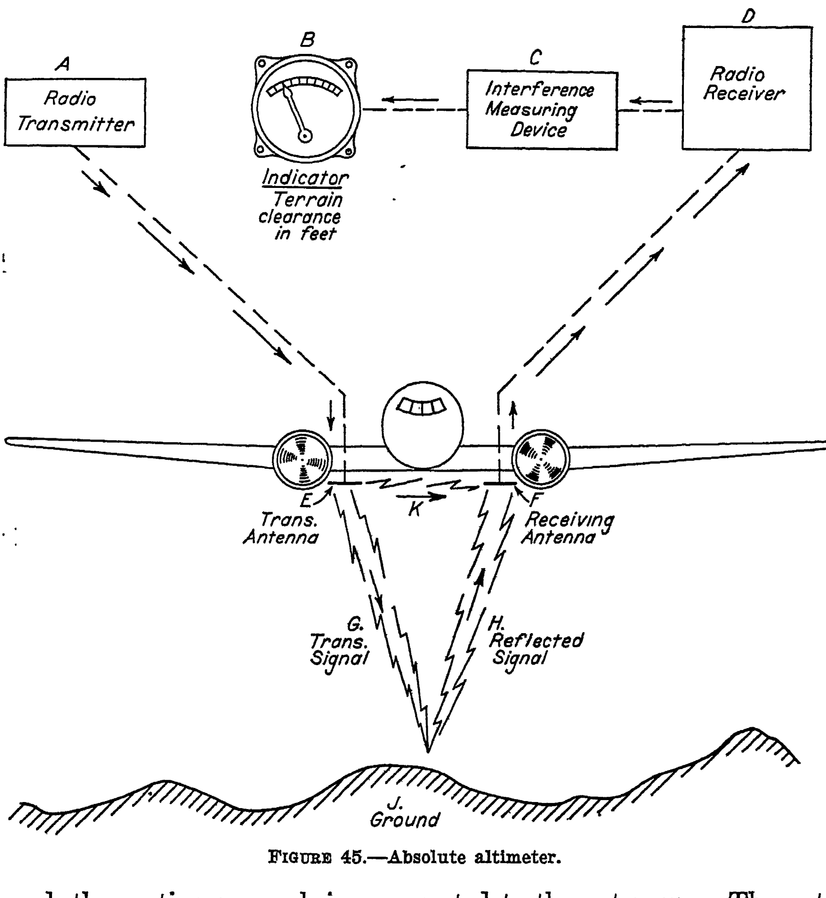

FIGURE 45.—Absolute altimeter.

used, the suction source being connected to the outer one. The outside air enters the inner case, is directed against the rotor, and exhausted through the exhaust ports in the housing to the outer case and thus to the suction source. A pendulum controls the air exhausting through two of the ports and stabilizes the housing so that the axis of the magnetic element is maintained in the vertical plane containing the magnetic meridian. The complete stabilization of the axis in this plane prevents any effect of the earth's vertical field,

thereby eliminating northerly turning error. However, some northerly turning error remains because the method of stabilization is not as yet perfected.

A magnetic element controls the air through the other two exhaust ports and stabilizes the rotor axis in a magnetic east-west direction. This gives the reference direction for determining the heading of the aircraft.

The pendulum-controlled and magnetic-controlled air jets both exert comparatively weak torques, causing the gyroscopic axis to follow slowly. Thus, horizontal accelerations and vibration will not deflect the gyroscopic axis appreciably from its average orientation.

FIGURE 46.—Photograph of gyromagnetic compass.

Because of the magnetic qualities of ball bearings it was necessary to use air bearings.

Provision is made for setting the rotor unit so that the proper heading is approximately indicated, thus reducing the time before reliable readings are obtained. A compensator, similar to that used in other magnetic compasses, is provided to neutralize the effect of the disturbing magnetic field produced by the magnetic materials in the aircraft. Compensating the installed gyromagnetic compass has proved to be a much slower process than with the magnetic compass. This is caused by the fact that it required some time for the magnetic element to bring the rotor and card unit to a position of equilibrium following each adjustment of the compensator. It has been proposed

that if practicable in the final design, a magnetic card compass with the compensator from the gyromagnetic compass be installed in the aircraft. The compensator can then be set more easily. For the compensation to be equivalent, it is essential that the compass magnets and compensator be in exactly the same relative position as the gyromagnetic compass magnets and compensator, and that the point of installation be identical for the two units. After the compensation

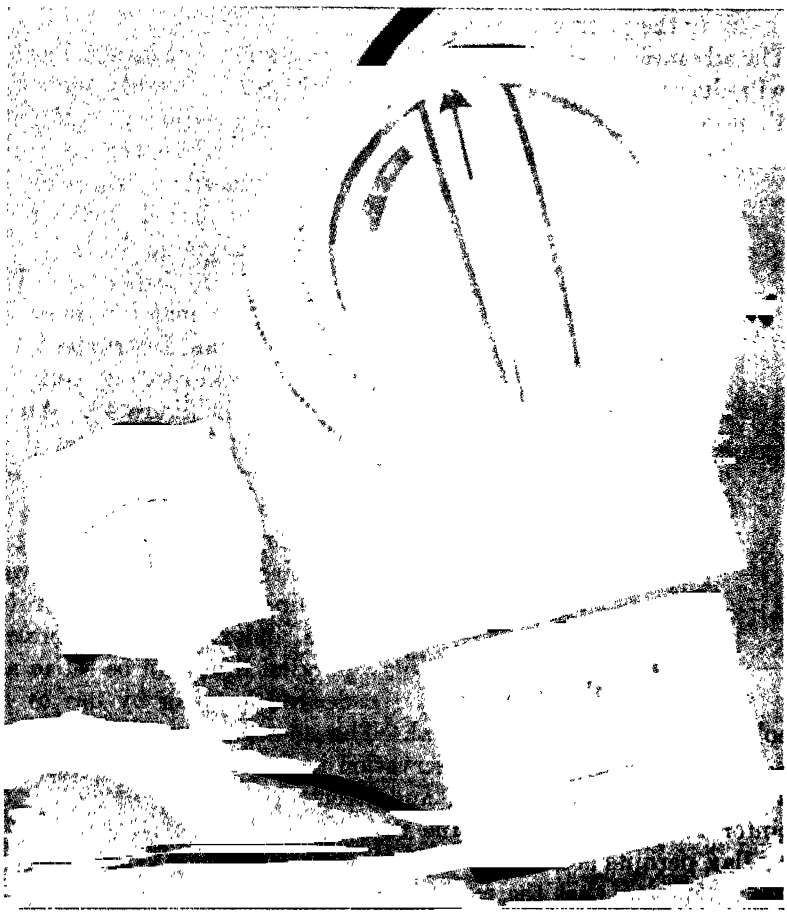

FIGURE 47.—"West" telemagnetic aircraft compass.

has been completed the gyromagnetic compass and the compensator are installed without disturbing the adjustment of the compensator.

Telemagnetic aircraft compass.—This type compass is shown in figure 47. A small condenser plate is secured to the compass needle and two other plates are within the compass bowl, in such a way that as the aircraft swings in azimuth the small or movable plate passes closely by, but always equidistant from the other two stationary plates.

The steering indicator is made exactly responsive to this capacity change by means of a vacuum-tube oscillator, supplying high-frequency current to the condenser-plate units. To set a heading, the entire bowl and its setting ring are rotated to the required number of degrees, thus displacing the angular relation of the three condenser plates. As the aircraft reaches the proper heading, the plates will again be in their normal relation, with the indicator hand then being on its zero or "on-course" position. This heading may then be steered by keeping the pointer on zero.

The advantages of this type of compass are: (1) The large spherical bowl reduces turbulence of the damping fluid; (2) it is truly aperiodic, with no overswing; (3) it may be located in a region of minimum deviation, while the indicator may be placed anywhere on the instrument board without regard to magnetic fields.

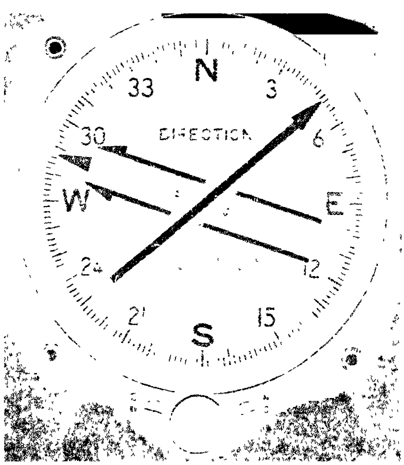

FIGURE 48.—Direction indicator.

Direction indicator.—This instrument, manufactured by the Kollsman Instrument Co., is a vertical-reading compass, as shown in figure 48. An indicating pointer, actuated by the internal magnetic element, rotates in front of the dial. Its position shows the heading of the aircraft (figure 48 shows a heading of 49½°). The reference index, with cooperating parallel lines, can be set to any desired heading by use of the knob at the bottom of the dial. The advantages of this type of compass are: (1) Compass observation is made simple by setting the index to the desired heading and steering the aircraft so that the pointer remains parallel to the reference lines; (2) the absence of parallax permits accurate observation from any angle; (3) there is so little overswing that the magnetic element is very nearly aperiodic.

Stall-warning indicator.—Referring to figure 49, the stall-warning indicator employs a total-head tube located close to the wing surface in a region wherein local stalling occurs before the main portion of the wing stalls. The artificial production of a localized stalled region is accomplished by means of a sharp leading edge extending a few inches along the span, as shown. An abrupt drop in the total pressure relative to a static reference, taken at some convenient point, occurs at the stall in this region. This drop in total pressure causes

the contraction of a pressure cell to which the total-head tube and the static orifice are connected and closes an electrical circuit that actuates a warning signal.

OPTICAL DRIFT SIGHTS

Serious attention is being given to the development of drift sights. It has been found impracticable to take a drift observation from an exposed position at speeds of 150 knots and above. This has led

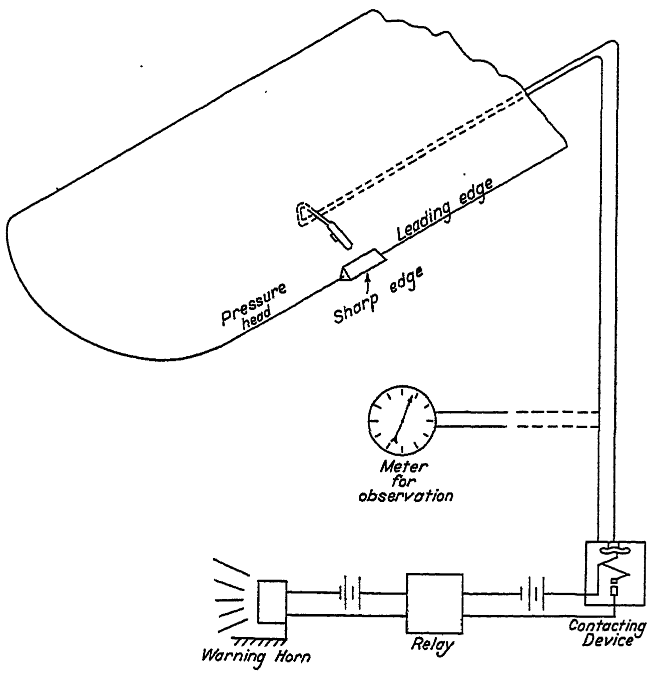

FIGURE 49.—Diagram of a stall-warning device.

to the development of an optical sight that can be used from a protected position.

To more accurately determine the relation between the axis of the aircraft and the apparent motion of the earth beneath it, through the use of optical drift sights, continues to be the subject of experimentation and test.

The following more recent developments may be cited:

Astigmatizers.—It has been found that an astigmatizer placed in the focal plane of an optical drift sight, draws out all points of light that can be seen on the surface in straight lines that are parallel to the grid lines. As the drift sight is turned in azimuth the astigmatized lines remain parallel to the grid lines and any drift of the plane shows the grid lines moving to the right or left. This indicates the

direction of drift, and the sight is turned until there is no movement in either direction of the grid lines and the astigmatized lines.

Adjustable slots.—It has been found in test that at high altitudes and low magnification it becomes difficult to see speed lines on the surface of the water sufficiently clear to take drift. In order to reduce the field and to speed up this apparent motion an adjustable slot has been developed that will reduce the field to a very small width. This slot is perpendicular to the grid line and should be adjusted to give the observer the required field at different altitudes. It is then apparently easy to observe the flow of water and to rotate the drift sight so that the grid lines are parallel to the flow.

Chapter III

DEAD RECKONING NAVIGATION

Dead reckoning and pilotage are so closely related that it is hard to differentiate between them. Pilotage consists of keeping the aircraft's position established by maintaining visual contact with known objects on the earth's surface. If the aircraft always remains within sight of some object, such as a lighthouse, point of land, beacon, or city, it can always ascertain its exact location relative to it. Dead reckoning, or the original expression, deduced reckoning, as the name implies, consists of determining the aircraft's location by means of estimating the true track and ground speed. This may be done by measuring the speed and drift experienced during the run between known objects or computed by applying the necessary corrections for the measured wind. It is the basis of all navigation, and other types of navigation may be said to be supplements of dead reckoning. In it the three elements, course, speed, and wind, must be properly computed if the resultant track and speed are to be accurately determined.

Whenever practical, the accuracy of the estimates are checked by the use of known objects, celestial observations, or radio bearings. The information thus gained is utilized in making new estimates. Dead reckoning thus divides itself into two phases:

1. The prediction of the course to be steered and an estimate of the ground speed.
2. The determination of the errors in the original estimates and the application of a correction for the indicated errors.

Considerable misunderstanding of dead reckoning has grown up in the last few years. If the expression "deduced reckoning" were used, this confusion would be eliminated. It is not the predicted course and speed of the aircraft, but rather track and speed derived from the estimates of the navigator. In other words, the course line between two points is not the dead-reckoning line. Errors due to poor steering, to inaccurate wind determination, and to instrument errors will cause the actual track to deviate from the desired course. The accuracy of the dead reckoning will be dependent on the navigator's solution of the forces affecting the aircraft and his estimate of the errors due to piloting and inaccurate instruments.

It must not be assumed that read-reckoning navigation is necessarily inaccurate. In actual practice remarkably accurate results

have been attained by careful calibration of instruments and an exact determination of the forces acting on the aircraft in flight. Because of the high speed and visibility inherent in aircraft, most navigators are prone to accept relatively large errors in dead reckoning as of little importance. This attitude is probably due to the relatively restricted range of flights compared with the visibility range. As the flight range increases the necessity for greater accuracy becomes more urgent. It is undoubtedly true that the demands for increased accuracy will cause better equipment to be developed.

In the same manner that every movement of a surface vessel involves a navigation problem, every aircraft flight should be, and actually is, a navigational flight. In most cases it is merely a dead-reckoning problem combined with pilotage in which the problems are solved mentally. For training purposes these flights afford an excellent opportunity to acquire skill and speed in estimating wind and correcting for varying conditions. The limitations of mere judgment should be appreciated and every effort made to acquire experience in the use of instruments for navigating. In naval aviation, where most of the flying is over water, pilotage is of little use and dead reckoning becomes the primary means of locating the aircraft geographically.

The fundamental dead-reckoning problem is a flight from one point to another. The navigation involves merely the correction of the true course for the wind and compass errors and the computation of ground speed.

The actual steps the navigator should perform are:

1. Plotting of the desired true course.
2. Correction of the indicated altitude and air speed.
3. Solution of wind problem preferably by three-course method.
4. Solution of speed diagram to obtain heading and ground speed.
5. Conversion of true heading to proper compass heading.
6. Departure.
7. Observation of the drift angle on base course at frequent intervals to detect any change and the determination of the new wind when a change occurs.

If the above steps are performed accurately and a careful course steered at a constant speed, the aircraft should arrive at its destination at a definite predictable time.

The Mk. III aircraft navigational plotting board has been adopted as standard navigation equipment; thus each type of problem taken up will be explained in connection with this board.

This chapter has been divided into sections and at the end of each section, one problem of each type is presented. The student should concentrate on each type using numerical values of his own until he is able to work that type in the time indicated.

The data given in figure 50 will be used in this chapter wherever applicable and should be transferred by the student to his Mk. III plotting board.

In the text, illustrations, and problems, unless otherwise stated, the values given are TRUE for all wind directions, courses, tracks, headings, bearings, air speeds, and altitudes. Unless otherwise stated, the pressure altitude and the true altitude will be assumed to agree for all practical purposes.

Wind

Altitude:	*From*	*Force*
Surface	226	16
1,000	240	18
2,000	258	20
3,000	280	25
4,000	317	28
5,000	005	39

Air speed calibration

Calibrated air speed	70	80	90	100	110	120	130	140	150	160
Indicated air speed	72	84	96	106	114	122	130	138	145	154

Deviation

Magnetic heading	0	30	60	90	120	150	180	210	240	270	300	330
Compass heading	2	33	64	93	122	150	179	208	237	267	299	330

FIGURE 50.—Tables used in working dead reckoning navigation problems.

The following equipment is used by the navigator in dead reckoning:

An accurate timepiece.

An accurately calibrated air speed meter.

An accurately calibrated compass.

An accurate altimeter.

A strut thermometer.

A Mk. VIII computer to facilitate correcting (or uncorrecting) his instrument readings and working speed-time-distance computations.

A plotting board to replace plotting sheet, parallel rulers and dividers.

Two or more sharp pencils with erasers (blue lead or No. 2 black lead).

A log sheet.

Precautions necessary in handling this equipment are as follows:

Keep the timepiece properly wound and set.

Keep up-to-date calibration cards posted in the cockpit.

Avoid scratching the celluloid surface of the plotting board.

Avoid jarring the metal disk on the back of the board since any shock will elongate the hole in the center and result in serious inaccuracy.

Keep sharp pencils readily available (it is wise to keep a mechanical pencil attached nearby in the cockpit with a string).

Keep an accurate, orderly, and complete record of all data required on the log sheet. Leave nothing to memory.

The Mk. III board has no magic property that prevents the navigator from making personal errors, which are undoubtedly the chief cause of getting lost.

A peculiarity of most errors is that their effect is double the correction made. For instance, to apply a *15°* variation incorrectly would introduce an error of *30°*. But it is not enough simply to be accurate. These computations must also be handled with speed. If it takes a pilot *3* minutes to carry a minor computation to a correct solution it will take him an hour to make 20 computations and it may well happen that this many will be involved in a flight of 1 hour's duration. It should not take over 10 seconds to handle any single minor computation and get accurate results. It should be borne in mind that to check any one of these computations it is only necessary to work it backwards. It is very wise to do so when time permits.

MK. VIII COMPUTER

The Mk. VIII computer is a circular slide rule than can be set to show a proportion between minutes and miles. For all computations the time must be reduced to minutes and the decimal point must be placed as required. For example *1* hour and *50* minutes must be used as *110* minutes, and since there is no figure *110* on the scale, the figure *11* must be used.

All other values in the same problem must be handled accordingly and in the same manner *11* must be used to represent *1.1*, or *1100*.

There are four forms of speed-time-distance problem. Each of the following is demonstrated in figure 51:

(*a*) Ground speed is *86* knots. How far will the aircraft travel in *30* minutes?

Answer: Set speed index arrow on the minutes scale to point to *86* on the miles scale, showing that the aircraft travels *86* miles in *60* minutes. Then refer to *30* on the minutes scale and opposite it will be found *43* on the miles scale.

(*b*) Ground speed is *86* knots. How long will it take to travel *136* miles?

Answer: Set speed index arrow to *86* on the miles scale. Then refer to *136* on the miles scale and opposite it will be found *95* on the minutes scale.

(*c*) In *37* minutes the aircraft travels *53* miles. What is the speed?

Answer: Set *37* on the minutes scale opposite *53* on the miles scale. The speed index arrow will point to *86*.

(*d*) In *23* minutes the aircraft travels *33* miles. How far will it travel in *30* minutes? How long will it take to travel *160* miles?

Answer: Set *23* on minutes scale abreast *33* on miles scale. Then refer to *30* on minutes scale and opposite it will be found *43* on the miles scale. Refer to *160* on the miles scale and opposite it will be found *112* on the minutes scale.

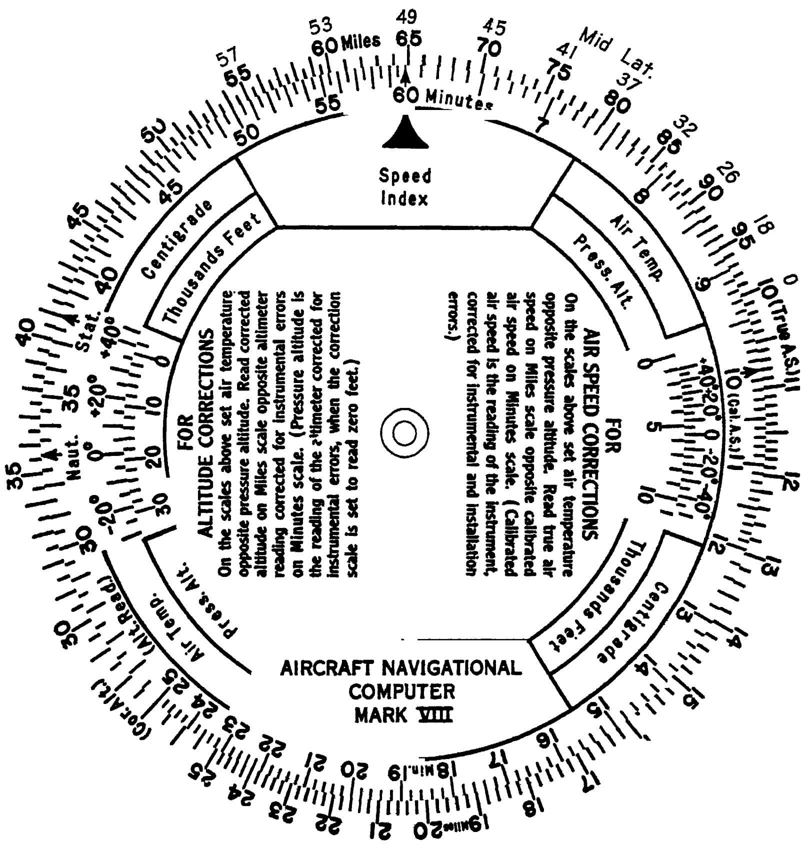

FIGURE 51.—Aircraft navigational computer Mk. VIII.

Correcting or uncorrecting the air speed is accomplished as shown in the examples:

(*a*) A pilot is flying at a calibrated air speed of *120* knots at a pressure altitude of *19,000* feet where the temperature is + *10* C. What is the true air speed?

Answer: Set +*10* on the (Air Temp.) scale opposite *19,000* in the (Press. Alt.) window. Then refer to *120* on the (Cal. A.S.) scale and opposite it find *172* on the (True A. S.) scale.

(*b*) A pilot wishes to make good a true air speed of *150* knots at a pressure altitude of *19,000* feet where the temperature is $+10$ C. At what calibrated air speed should he fly?

Answer: Set + *10* on the (Air Temp.) scale opposite *19,000* in the (Press. Alt.) window. Then refer to *150* on the (True A. S.) scale and find opposite it *104.8* on the (Cal. A. S.) scale.

PROBLEMS

1. Air speed meter reads *110;* what is the calibrated air speed?
2. You wish to fly at a calibrated air speed of *122* knots. At what indicated air speed must you fly?
3. At a pressure altitude of *12,000 feet, temperature 0°* C. you are flying at an indicated air speed of *97* knots. What is your true air speed?
4. At a pressure altitude of *10,000* feet, temperature plus *20°* you wish to make a true air speed of *135* knots. At what indicated air speed will you fly?
5. You leave the ship at *1027* and turn at *1114*. How long have you been on the first leg?
6. At *1249* you start out on the first leg of a scouting problem. You expect to turn *82* minutes later. At what time will you turn?
7. You travel for *93* minutes at a ground speed of *106* knots. How far have you traveled from your starting point?
8. In *2* hours and *14* minutes you cover *177* miles. What is your ground speed?
9. If you travel *23* miles in *14* minutes how long will it take to cover *84* miles? How far will you go in *72* minutes?
10. You leave Pensacola at *1338*. At *1405* you are *68* miles from Pensacola. What is your ground speed?

Total working time for the above problems *8* minutes.

USE OF AIRCRAFT NAVIGATIONAL PLOTTING BOARD

The following general rules apply to the Mk. III board in getting the most accurate results:

Have the board absolutely clean before starting to work.

Do as much of the plotting in advance of taking-off as possible.

Draw fine lines. Wide lines are inaccurate and hard to erase.

Identify each point by a small dot with a circle around it.

Always use the board with the north end away from you since that is the way it fits in the aircraft.

Label completely all lines and points immediately after they are drawn in addition to recording the same information in the log sheet.

See that grid and disk are snug on their pivot.

In plotting, only true directions and air speeds must be used.

Wind is always expressed in the direction from which it blows.

Position is always expressed with reference to some other known position or line. Thus, Pensacola is in lat. *30°21′* N., long. *87°16′* W. In other words, it lies *30°* and *21′* north of the equator and *87°* and *16′* west of the meridian of Greenwich, England. Or Pensacola may

be said to bear *080°* from New Orleans, distant *147* miles. In this case the bearing is simply the direction or slope of a straight line from New Orleans to Pensacola.

Direction is always expressed in degrees, clockwise from north (0) to north (360). Distance is always expressed in nautical miles.

Construction of small area plotting sheet.—Select the latitude to the nearest whole degree approximately in the middle of the operating area. Assume this to be Pensacola and vicinity, and use midlatitude *31°*. Referring to figure 55, on page 92, set the true index of the grid *31°* below *90* (at *121°* which is *90°* + *31°*) and draw from this point a straight line through the center of the board, as shown in the illustration. Place a mark on this line at each multiple of *60*. Set the true index to north. Draw a north-south line through each mark on the diagonal line. Draw an east-west line through each multiple of *60* on the north-south line that runs through the center of the board. Label the middle east-west line *31°* N., the middle north-south line *89°* W., and the other lines accordingly. The latitude and longitude lines are now laid out for this area with the longitude lines properly spaced according to a Mercator projection for the midlatitude. Since it covers a small area, and is equipped with a compass rose (the outside ring marked off from *0° to 360°*) it is a small area plotting sheet.

If geographical points are added, coast line, islands, etc., a map or chart of this area is constructed. A geographical point is placed on the plotting sheet as follows: Set the true index along the diagonal line and *16* units to the left of longitude line *87* west make a cut on the diagonal line. Set the true index to north and draw a short line in the approximate latitude of Pensacola exactly in line with the cut on the diagonal line. This will establish the longitude line that Pensacola lies on since it is *16* minutes west of long. *87* west. Then pick off lat. *30°21′* N., and draw a short east-west line through the short line just drawn and where these two lines cross is the location of Pensacola.

It will be found advantageous in constructing a chart to use a pencil of different colored lead than that expected to be used in working out any subsequent problem since many additional lines will be involved and it is highly desirable to keep them distinct from one another. A straight edge may be used since this operation is usually performed before take-off.

In determining the latitude and longitude of any point on the chart it is only necessary to set the index to north and note how many minutes the point lies above the latitude line next below it. Then make a cut on the diagonal line exactly in a north-south line with the point, rotate the grid to line up the index line with the diagonal line and

find how many minutes the cut is west of the longitude line next to the right. As an illustration, New Orleans is found to lie in lat. 29°58′ N., long. 90°03′ W.

By the incorporation of a modified cosine scale on the Mk. VIII computer, miles of longitude may be converted into minutes of longitude and reverse, by using the required midlatitude. As shown in figure 51, angular values on the "miles" scale are added in accordance with the following table (from H. O. Pub. No. 9, Bowditch, table 6).

Miles	0 10	18 95	26 90	32 85	37 80	41 75	45 70	49 65	53 60	57 55	60 50

This additional scale is labeled "midlatitude." By setting the arrow marked at 10 on the disc scale to the proper midlatitude, miles of longitude may be read directly opposite minutes of longitude, or vice versa.

Bearing and distance.—Consider that the bearing and distance of New Orleans from Pensacola is to be found. Plot in New Orleans in the proper latitude and longitude (29°58′ N., 90°03′ W.) as shown in figure 55. Rotate the grid until some line on it coincides with an imaginary line between New Orleans and Pensacola, or is parallel to it. Then the true index *lying in the same direction from the center of the board as New Orleans lies from Pensacola* will indicate the bearing to be *261°*. The distance between the two points measured along this same line is shown to be 147 miles.

It is also frequently necessary to plot in on the chart a point, knowing its bearing and distance from some other established point. In this case rotate the grid to the desired bearing, indicated by the true index. Then measure off the distance from the known point along the nearest line on the grid parallel to the true index line and there make a dot with a circle around it to indicate the required point. Thus, Mobile may be plotted in on a bearing of 297°, 44 miles distant from Pensacola.

The easiest, quickest and most accurate way in which to obtain a bearing is to head directly at the object for a few moments and read the compass. Then return to the original heading so as not to get off the course appreciably and correct the compass reading just obtained, for deviation and variation. The course of a surface ship may be estimated very closely in a similar manner by heading parallel to the ship and correcting the compass reading obtained. The direction of the surface wind may likewise be determined by heading directly into the wind. Distances can be judged fairly well by practice and it helps to take into consideration any information you have on the visibility or the distance you traveled from your own ship

before it disappeared from view. The speed of a surface ship can be estimated by practice in observing the bow wave, wake, set in the water, etc. of ships making known speeds. There is a definite relationship between the length of the vessel and the distance from the bow that the bow or stem wave forms.

PROBLEMS

11. The compass reads *358°*. Variation *4°* E. What is the true heading?

12. What compass heading must be steered to head *186°* T? Variation *16°* E.

13. You sight a ship and head directly toward it and read the compass. It reads *097°* What is the bearing of the ship? Variation *6°* W.

14. You head parallel to ship and read the compass. It reads *135°*. What is his true course? Variation *6°* W.

15. Ten minutes after leaving the ship you head directly toward it and your compass reads *243°*. What bearing have you made good from the ship? Variation *10°* W.

Working time for above problems *6* minutes.

16. A pilot heads exactly parallel to a railroad at a point where the tracks are shown on the chart to lie in a direction of *334°*. His compass reads *339°*. Is his compass accurate on this heading? Local variation *4°* E.

17. The NAS seaplane tower and the WCOA broadcasting tower form a range of *046°*. When a pilot sights both objects in line and directly ahead of him, his compass reads *045°*. Is his compass accurate on this heading? Local variation *4°* E.

18. A pilot on a cross-country flight encounters conditions that force him into unfamiliar territory off his course. He recognizes no landmarks, but sights a railroad crossing a stream. He heads parallel to the railroad and the compass reads *032°*. He heads parallel to the stream and the compass reads *110°*. The variation is *15°* E. Reference to the chart shows three possibilities of this combination:

	Direction of railroad	*Direction of stream*
Centerville (approximately)	*050°*	*140°*
Middletown (approximately)	*050°*	*130°*
Franklin Forks (approximately)	*020°*	*130°*

Which is his most likely position?

Working time for above problems *6* minutes.

19. You sight a lighthouse bearing *210°*. After traveling *14* miles on a track of *115°*, you find the lighthouse bears *220°*. How far are you from the lighthouse?

Working time *2* minutes.

20. By means of his loop antenna, a pilot takes a radio bearing of WCOA at *1000* and finds it to be either *085°* or *265°*. In the next *10* minutes he travels *15* miles due north and then takes another bearing which he finds to be either *095°* or *275°*. What is the bearing and distance of WCOA at *1010?*

Working time *2* minutes.

21. WWL bears *260°* distant *170* miles from Pensacola radio range station. At *1100* a pilot "riding" the Pensacola beam *355°* mag. secures an RDF bearing of WWL, of *243°*. How far is he from Pensacola? Variation *4°* E. Another pilot secures a bearing of both stations at about the same time. WWL bears *310°* and Pensacola bears *044°*. How far is he from Pensacola?

Working time *5* minutes.

22. Pensacola is in lat. *30°21′* N. long. *87°16′* W. Mobile is in lat. *30°41′* N., long. *88°02′* W. Find the bearing and distance of Mobile from Pensacola. Marianna bears *78°* and is *108* miles from Pensacola. What is its latitude and longitude? A ship leaves Pensacola at *1130* on course *200°*, speed *20* knots. What should the bearing and distance of Mobile be at *1300?*

Working time *10* minutes.

23. Own position at *0800* lat. *37°15′* N., long. *127°25′* W. Objective's position at *0800* lat. *39°25′* N., long. *126°55′* W. Own course *076°*, speed *22* knots. Objective's course *082°*, speed *20* knots. What is the bearing and distance of the objective at *0800?* If both ships maintain course and speed, what will be the bearing and distance of the objective at *0930?*

Working time *10* minutes.

24. The carrier is on course *190°*, speed *24* knots. A pilot leaves the carrier in lat. *37°20′* N., long. *142°10′* W. at *1130* and scouts on a course of *305°* at a ground speed of *92* knots. At *1247* he scouts on a course of *255°* at a ground speed of *104* knots. At *1312* he sights a derelict *15* miles away bearing *275°*. What is the position of the derelict. What is its bearing and distance from the carrier?

Working time *12* minutes.

TRACKING

There are two things that put distance between an aircraft and its point of departure: motion of the aircraft through the air and motion of the air itself. What actually happens may be illustrated by considering the motion of a boat through water which is also in motion. Assume that a boat leaves point "*a*," as in figure 52, headed due east to cross a stream flowing from the north. If the water were not moving, in any given time the boat would travel due east through the water to some point such as "*b*." But since the water *is* moving, the

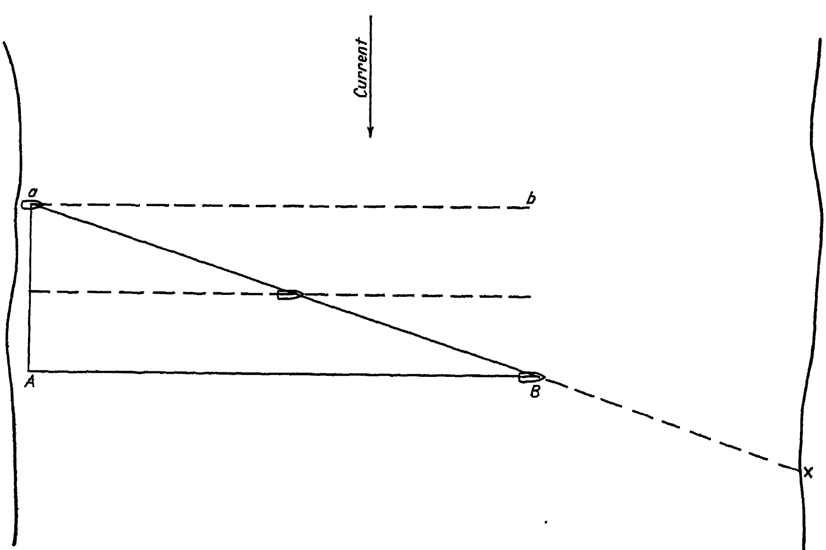

FIGURE 52.—Motion of a boat across a stream.

line *a—b*, with the boat on it, will move downstream with the water and appear as the line *A—B*. Thus, the boat in this length of time has traveled over the ground from *a* to *B*. The boat has also traveled through the water from *A* to *B*. The water itself has traveled from *a* to *A*.

It will be observed that if the boat continues its motion, it will ultimately arrive at a point *X* along a continuation of its track over the ground. At no time has the boat been headed in the direction of point *X*.

Now consider an aircraft in this connection. Assume a pilot desires to fly from field *E* to another field *X*, which is due east of *E*, and there is a north wind blowing, as in figure 53. Using any set speed through the air, if there were no wind blowing, the aircraft could head in any desired direction and thus arrive at any point on the circle "*p*" in 1 hour. Since the wind is blowing, however, this

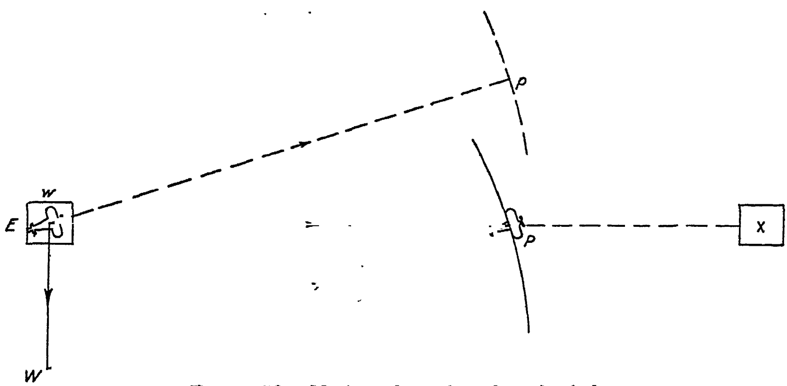

FIGURE 53.—Motion of an aircraft and wind.

circle will move south in 1 hour by the amount *E—W*. Since the aircraft must be somewhere on the circle and to fulfill the requirements, somewhere on the required line of travel *E—X*, it must be at their point of intersection *P*, and the line *W—P* will indicate the direction the aircraft must head. *E—W* represents the force and direction of the wind. *P* shows the position of the aircraft at the end of 1 hour, so with respect to the point on the earth that it left, *E*, it travels over the line *E—P*, which may therefore be called course or track (direction of motion over the ground) and ground speed (rate of motion over the ground). With relation to the point in the air that the aircraft left, it travels the line *WP*. The *direction* of *WP* indicates the heading of the aircraft and the *length*, the air speed. The angle *EPW* is the *wind correction angle*, or *drift* angle. It is the number of degrees to the right of the heading at which the pilot should sight field *X*, or the number of degrees he should see field *E* to the right of his tail. Now it is apparent that

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if he knows how much of the total distance from E to X the aircraft should travel in 1 hour, it will be a simple calculation to predict when the aircraft should arrive at point X.

What has been derived may be called a speed diagram since it shows predicted distances traveled in 1 hour. It is the basic and fundamental construction of all aerial navigation and it is of the utmost importance that the student understand it thoroughly. It will now be drawn over again and labeled in the conventional manner, as in figure 54. E represents *any* point on the earth; W represents the predicted position of the wind after blowing *1 hour* from point E; P represents the predicted position of the aircraft *1 hour* after leaving point E. It is very important to note that each line furnishes two essential items of information: The slant represents a direction, while the length represents a speed. Course and heading are always in the same *general* direction.

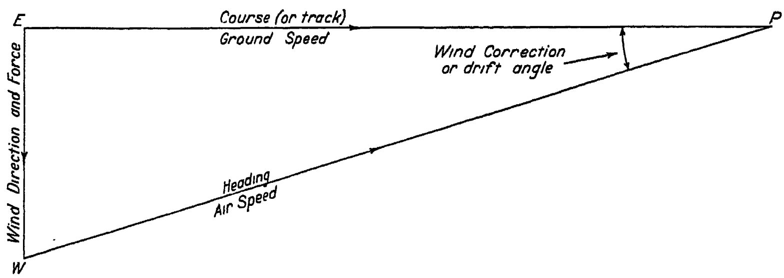


FIGURE 54.—Conventional speed—diagram for aerial dead reckoning navigation.

Tracking is the problem that a new pilot will be called upon to perform most frequently in a squadron. He is not responsible for setting a course to scout a given area, but as wing man he must accompany the section leader who does have this responsibility and he must be able to determine from his instrument readings, correction tables and information on the ship movements and wind, the track being made good so that he will at all times know the position of the section. This is absolutely essential for he must be prepared to return to the ship independently if required by such a contingency as getting separated from the section, a forced landing of one of the other aircraft, or some casualty to his own engine or aircraft. In addition, he may be called upon to take the lead in case the section leader becomes lost. Furthermore, his aircraft may have to assume the responsibility of reporting his own position in case of casualty to the leader or leader's radio.

In a sense, every type of aerial dead reckoning problem is a tracking problem, even for the leader of the section. In many cases, it will be impossible or undesirable to make good the courses previously calculated to scout the required area. Then he will have to track

himself, that is, record in his log sheet and geographic diagram any change of his assumed track caused by a change of wind, or a detour around bad weather. A plot of the track must therefore be made by every pilot in the section as the problem progresses and these plots should be identical if all pilots handle the information correctly.

First consider a typical problem such as a student may encounter at Pensacola. As wing man of a section of three airplanes, he takes off with the information on wind and the calibration of his instruments which is shown in figure 55 filled in on his log sheet. In addition he knows from previous reference to a chart that the variation in this area is 4° east. In the air he records the following instrument readings on his log sheet as soon after take-off as the section is opened out and steadied down on the first leg:

Departure time *1000.*
Compass heading *008°.*
Indicated air speed *117 knots.*
Pressure altitude *3,000 feet.*
Temperature *plus 12° C.*

Prior to take-off the latitude and longitude lines of a small area plotting sheet of this area have been laid off on the Mk. III board, and the position of the point of departure, Pensacola, has been indicated in the proper place. The first step in the air after reading and recording the instrument readings is to convert these into true values that may be used in drawing a speed diagram. Thus, by reference to the correction tables and Mk. VIII computer fill in the following on the log sheet:

Magnetic heading *006°.*
True heading *010°.*
Calibrated air speed *114* knots.
True air speed *120* knots.

The next step is construction of the first speed diagram. Pick out from the wind table the wind known to exist at your altitude, *3,000* feet, and draw a line *to the center of the board* representing this wind in direction and force. Put an arrow on it to indicate its direction and label the point at the center "W" and the other end of the line "E." Write the word "wind" alongside the line. From "W" draw a line representing the true heading and true air speed of the airplane. Place an arrow on it to show its direction, label it WP and alongside the line write "heading 010°," "air speed 120 knots." Then draw the line EP, place an arrow on it pointing in the same general direction as the heading-air speed line. Find the direction of the line from the true index and write alongside the line "track 022°." Find its length and write alongside "ground speed 123 knots." Then write both these values in the proper spaces on the log sheet.

With the grid still set with the true index indicating the track found in the speed diagram, draw a line parallel to the track, from Pensacola, the point of departure. This line will then show the computed path over the ground that the airplane will travel as long as the original conditions are maintained. In order that the position of the airplane may be predicted for any future time, make cuts on this track line for time intervals in advance.

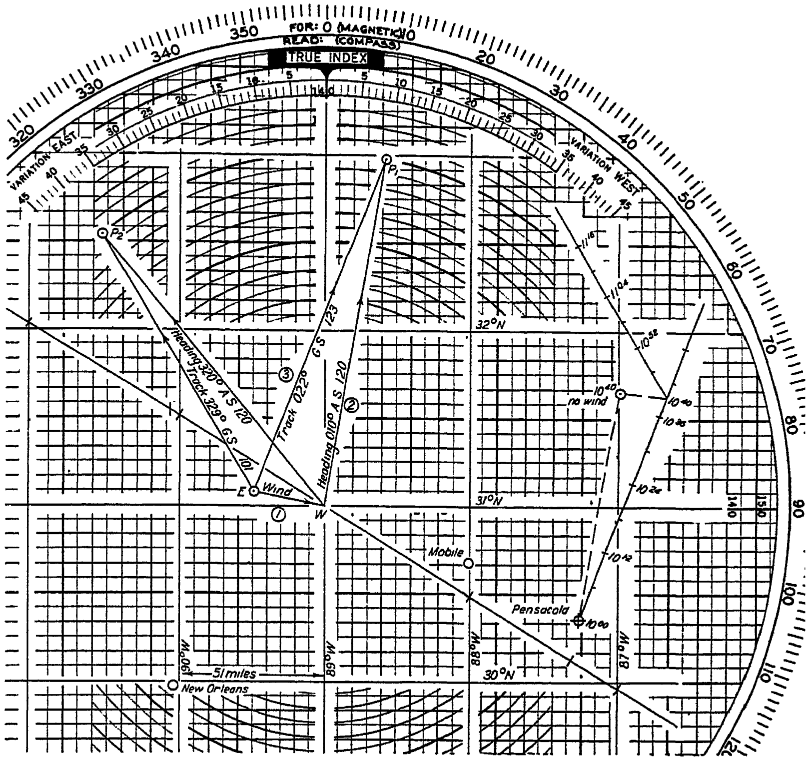
Six minutes is a convenient interval, since the run for this period is one-tenth the ground speed.

Now, assume that the leader changes heading at *1040*. This should be immediately entered in the log sheet as "departure time" under second leg. The remainder of the blank spaces in the first leg can now be filled out as follows:

Minutes on leg *40*.
Miles on track *82*.

The end of the first leg is indicated on the track line drawn from the point of departure and this should be labeled with the time. Now that the first leg has been plotted geographically on the chart, a simple check can be performed to ascertain the accuracy of the work. From the point of departure, draw a broken line representing where the aircraft would have gone in 40 minutes had there been no wind blowing. This line will be parallel to W—P, the heading and air speed line, and the length will be determined on the Mk. VIII computer using true air speed and minutes on leg. The point determined by this broken line will be the "no wind" position. Then it is only necessary to apply the value of the wind equal to 40 minutes to show how far the wind moved the airplane in the same length of time from its "no wind" position. The length of this second broken line will be determined on the Mk. VIII computer as above and the line will be parallel to east-west, the wind line on the speed diagram. The end of this line should coincide with the position of the airplane previously computed on the track line. If it does not, an error is indicated in the work and the computations should be rechecked.

With the new heading another speed diagram is constructed and from this a second leg is drawn in the geographic plot starting from the end of the first leg as shown in the illustration. This process is carried on as long as the flight lasts to show the pilot his estimated position at all times. The standard procedure is to draw *E—W* always to the center of the board, and by using the center exclusively for the speed diagram or diagrams, speed and accuracy of plotting are greatly enhanced. The latitude and longitude lines should be so drawn and labeled that the maximum area is allowed for the geographic plot without interference with the speed diagrams at the center of the board. The geographic plot is essential to show the continual progress of the flight.



Wind	From	Force	Ship movement			
			Time	Course	Speed	Miles
Surface	226	16				
1,000	240	18				
2,000	258	20				
3,000	280	25				
4,000	317	28				
5,000	005	39				

Log	Variation: 4° E.			
	1st leg	2d leg	3d leg	4th leg
Compass heading	008	316		
Magnetic heading	006	316		
True heading	010	320		
True air speed	120	120		
Pressure altitude	3,000	3,000		
Temperature	+12	+12		
Calibrated air speed	114	114		
Indicated air speed	117	117		
Direction of relative motion				
Speed of relative motion				
Miles of relative motion				
Track	022	329		
Ground speed	123	101		
Miles on track	82			
Minutes on leg	40			
Departure time	1000	1040		

FIGURE 55.—Construction of small area plotting chart and solution of a tracking problem.

It will be found very helpful before plotting the problem on the board to draw a rough sketch of the speed diagram with the various lines drawn approximately in the proper directions. With this as a guide, draw the speed diagram with all lines measured accurately. For the beginner, it is very important to label everything that can be labeled, including arrows for direction.

PROBLEMS

25. Wind *18* knots from *240*°T. An aircraft heads *180*° at a true air speed of *100* knots for *35* minutes; *085*° at same air speed for *20* minutes. Where is the aircraft at this time with reference to the starting point?

Working time *5* minutes.

26. Variation *6*° W. Press. altitude *3,000* feet. Temperature +*10*° C.

Time	*Compass heading*	*Indicated air speed*
1212	*008*°	*112* knots
1340	*122*°	*112* knots

At *1414* the airplane has a forced landing. What is the bearing and distance from the starting point?

Working time *12* minutes.

27. Ship's course and speed: *030*°, *18* knots. Variation *16*° E. Section leaves ship at *1020*, pressure altitude *2,000* feet, temperature +*15*° C., indicated air speed *105* knots. Compass heading *095*°. At *1135* section changes compass heading to *020*°. At *1155* section sights a disabled steamer *5* miles dead ahead. How far will the ship have to steam and on what course to render assistance to the steamer?

Working time *13* minutes.

28. Variation *16*° E. Ship's course *330*° and speed *22* knots. Airplane leaves ship at *0932* in lat. *34*°*15*′ N., long. *112*°*27*′ W. and steers the following compass headings:

Time	*Compass heading*	*Pressure altitude*	*Temperature*	*Indicated air speed*
0932	*263*°	*3,000* feet.	+*5*	*112* knots
1045	*310*°	*2,000* feet	+*10*	*116* knots

At *1102* a disabled ship is sighted *6* miles, bearing *280*° from the airplane. What is the disabled ship's bearing and distance from your ship? What is the latitude and longitude of the disabled ship?

Working time *18* minutes.

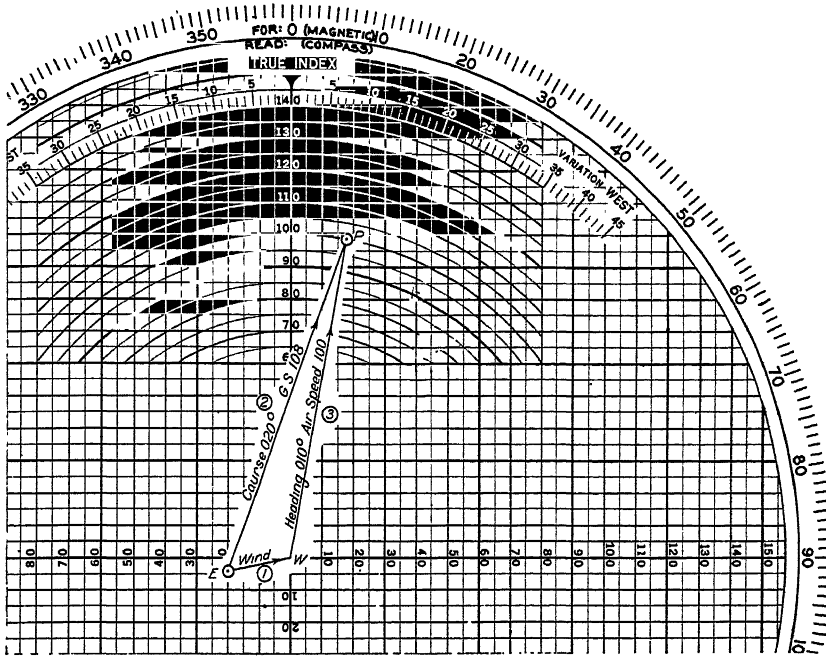
PLANNING A CROSS-COUNTRY FLIGHT

A flight from Pensacola to Greenville is to be made under the wind conditions shown on the log sheet, figure 56. On a chart of this area draw a straight line from Pensacola to Greenville. The direction of this line will be *020*°, which is the course that must be made good. The length of the line is *95* miles. The variation found from the chart is *4*° E. It is assumed that a true air speed of *100* knots at an altitude of *2,000* feet is used.

First, draw a line representing the wind at *2,000* feet *to the center of the board* and label it as shown in figure 56.

Second, draw EP in the direction of *020*°, the required course, to the 100-knot air-speed circle. Measure the length of this line—*108*

miles—which is the ground speed. Label this line and enter *108* in the proper space in the log sheet.



Wind	From	Force	Ship movement			
			Time	Course	Speed	Miles
Surface	*226*	*16*				
1,000	*240*	*18*				
2,000	*258*	*20*				
3,000	*280*	*25*				
4,000	*317*	*28*				
5,000	*005*	*39*				

Log	Variation: *4° E.*			
	1st leg	2d leg	3d leg	4th leg
Compass heading	*008*			
Magnetic heading	*006*			
True heading	*010*			
True air speed	*100*			
Pressure altitude	*2,000*			
Temperature	*+20*			
Calibrated air speed	*96*			
Indicated air speed	*102*			
Direction of relative motion				
Speed of relative motion				
Miles of relative motion				
Course	*20*			
Ground speed	*108*			
Miles on course	*95*			
Minutes on leg	*53*			
Departure time	*1000*	*1053*		

FIGURE 56.—Solution of a cross-country problem.

Third, draw WP and find its direction, which is *010°*, the required true heading, and enter in the proper space in the log sheet.

From the Mk. VIII computer it is found that to cover *95* miles on the course at a ground speed of *108* knots will require *53* minutes. This should be entered in the log sheet after "minutes on leg."

By applying variation and deviation, the required compass heading is found to be *008°*.

When the required altitude is reached, note the temperature. In the illustration it is assumed that it is plus *20°* C. By reference to the Mk. VIII computer, a calibrated air speed of *96* is shown, and reference to the air speed calibration card shows that it will be necessary to fly at an indicated air speed of *102* knots.

It is always well to maintain a geographic plot of a cross-country flight. The solution may be checked by means of advancing a no-wind position.

Although a course is laid down on the chart and marked off in increments to furnish checks on landmarks en route, any alteration of this course, or change of destination cannot be easily plotted on the chart while in the air. Thus, at times it is most valuable for the pilot to have his course laid down on his plotting board, together with the locations of several alternate fields. Then, if forced off the course or if required to abandon the original destination due to bad weather, it will be possible at any time to lay a course to some other field.

PROBLEMS

29. Wind *20* knots from *170°*. Find true heading to make good a course of *260°*, at an air speed of *80* knots. What is the ground speed and wind correction angle? If the air speed was *110* knots would the wind correction angle be the same?

Working time *6* minutes.

30. The Mobile-Atlanta radio range lies in a direction of *034°* mag. What compass heading should a pilot steer to fly this range at *3,000* feet at a true air speed of *135* knots? Local variation *4°* E.

Working time *4* minutes.

31. Variation *6°* W. An outlying field bears *170°*, distance *48* miles from base. Ceiling *2,500* feet. A pilot wishes to fly to outlying field and return immediately, at an altitude of *2,000* feet, true air speed of *85* knots. Temperature *5°* C. Find compass heading, indicated air speed, ground speed, and time for trip and return. Is a head wind encountered both going and returning?

Working time *10* minutes.

32. Find all the information necessary to fly *37* miles on a course of *313°*, *40* miles on a course of *224°*, and return to the starting point, commencing the flight at *1315*. Fly at altitude *4,000* feet, cruising at *90* knots. Var. *4°* E. Temp. *—5°* C.

Working time *12* minutes.

33. Var. *6°* W. Press. Alt. *3,000* feet. Temp. +*10°* C. Navigator logs the following information: Departed from base at *1212*.

Time	*Compass heading*	*Indicated air speed*
1212	*122°*	*112* knots
1246	*008°*	*112* knots

At *1414* orders received to return to base. What compass heading should be steered to return to the starting point at a true air speed of *150* knots? What is estimated time of arrival?

Working time *14* minutes.

34. At *0930* your ship bore *265°*, *90* miles from North Island, on a course of *035°*, speed *24* knots. You depart from the ship at *1015* for North Island, at *2,000* feet, true air speed *100* knots. Variation *16°* E. Temperature +*20°* C. Find compass heading, indicated air speed, and time of arrival.

Working time *6* minutes.

35. At *0842* an aircraft leaves ship in lat. *31°45′* N., long. *118°55′* W., to fly to North Island, lat. *32°45′* N., long. *117°15′* W., at an altitude of *2,000* feet, true air speed of *100* knots. Variation *16* E. Temperature +*15°* C. Required: Compass heading, indicated air speed, time of arrival. When North Island is sighted, should it appear to right or left?

Working time *12* minutes.

36. Utilizing the most favorable winds, find true headings and time for a cross-country flight, Pensacola to Tallahassee and return, at a true air speed of *110* knots. Tallahassee bears *088°*, *176* miles from Pensacola.

Working time *10* minutes.

37.

Guantanamo Bay:		*Port au Prince:*	
Lat	19°55′ N.	Lat	18°33′ N.
Long	75°09′ W.	Long	72°21′ W.

Wind from *045°*, force *15* knots. Variation *1°* E. Air speed *95* knots. What is compass heading and estimated elapsed time from Guantanamo to Port au Prince. If at the end of *1* hour and *32* minutes a forced landing occurred, give position (latitude and longitude) of forced landing.

Working time *12* minutes.

38.

Diamond Head:		*Barbers Point:*	
Lat	21°15′ N.	Lat	21°18′ N.
Long	157°49′ W.	Long	158°06′ W.

Wind *15* knots from *042°*. Variation *11°* E. True air speed *110* knots. Search for *100* miles south of Diamond Head and return to Barbers Point. What is compass heading and ground speed each leg? How much time is required for the flight?

Working time *12* minutes.

39.

Point Loma:		*Pyramid Head:*	
Lat	32°40′ N.	Lat	32°49′ N.
Long	117°15′ W.	Long	118°21′ W.

Wind *13* knots from *342°*. Air speed *90* knots. Variation *15°* E. Depart Point Loma at *0800* and proceed to Pyramid Head, then to a point *75* miles south of Pyramid Head and return to Point Loma. What is compass heading and ground speed for each leg? What is the time of return?

Working time *15* minutes.

DETERMINATION OF WIND FORCE AND DIRECTION

There are several methods of determining the force and direction of the wind:

1. Estimation, by observing the surface of the water.
2. When known landmarks or other fixes are available, find from the chart the track, and the distance made good in a given interval of time. Reference to the Mk. VIII computer will then give the ground speed.

Since the heading and air speed are also known, the line *WP* may be drawn from the center of the board to start the construction of a speed diagram. *EP* may then be drawn backward from point *P* to represent the track and ground speed. Then when *EW* is drawn it will complete the diagram and show the force and direction of the wind.

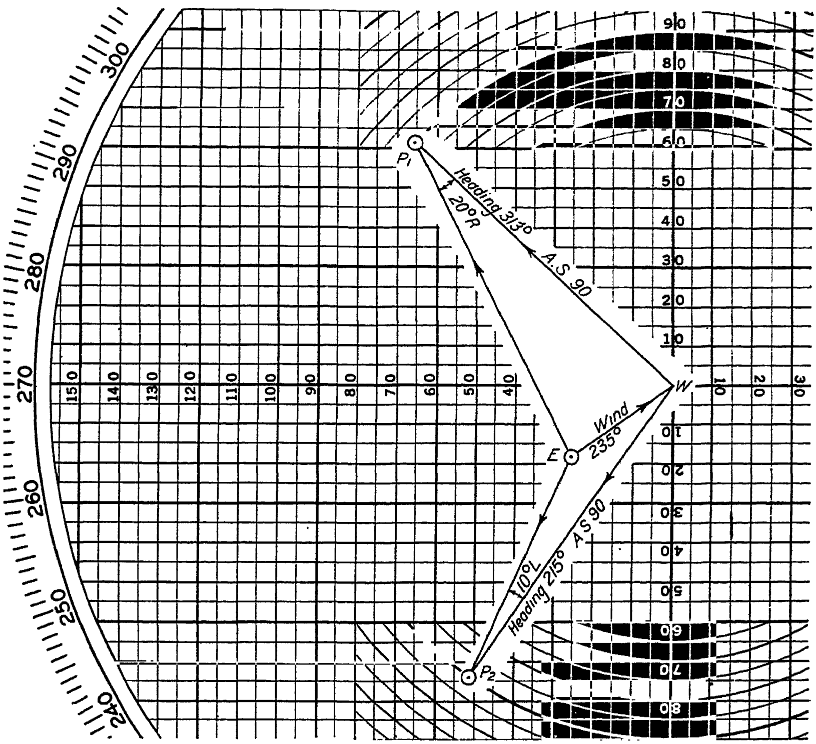
Example.—*19* minutes after leaving Pensacola on a true heading of *010°*, at an altitude of *2,000* feet at a true air speed of *100* knots a pilot passes over Berrydale, a town bearing *020°* distant *34* miles from Pensacola. What is the force and direction of wind?

Solution.—Knowing the true heading and air speed, plot *WP*. From the Mk. VIII computer find that *34* miles in *19* minutes means a ground speed of *108*. The track will be the bearing of Berrydale from Pensacola. With this information, draw *EP*. Complete the speed diagram by drawing *EW* and from this line find that the wind is *20* knots from *258°*. The construction for this problem is illustrated in figure 56, except that in this case *EP* represents track instead of course.

3. Solution by two or more drift sights:

Assume that a pilot has taken two drift sight observations on a smoke bomb, at an altitude of *4,000* feet, temperature of *0°* C., indicated air speed of *91* knots. On a compass heading of *308°* the drift angle was observed to be *20°* right and on a compass heading of *211*, *10°* left. First, correct the above instrument readings to show a true air speed of *90* knots and true headings of *313°* and *215°*. Construct the first speed diagram (fig. 57) by drawing WP_1 from the center of the board. From P_1 draw the track line *20°* to the right of WP_1 as shown. Next draw WP_2 in the second speed diagram and from P_2 draw the track line *10°* to the left. The intersection of the track lines drawn in each speed diagram will determine the position of *E*, and *EW* can then be measured to find the force and direction of the wind at 4,000 feet.

Since *E* depends on the intersection of two lines, it is important that the track lines be drawn as straight as possible. Inasmuch as drift observations are not always dependable, it is desirable to take a third sight and plot it in a similar manner as a check against the other two. All three should intersect in a single point if all work is



Wind	From	Force	Ship movement			
			Time	Course	Speed	Miles
Surface						
1,000						
2,000						
3,000						
4,000						
5,000						

Log	Variation: *4 E*			
	1st leg	2d leg	3d leg	4th leg
Compass heading	*308*	*210*		
Magnetic heading	*309*	*211*		
True heading	*313*	*215*		
True air speed	*90*	*90*		
Pressure altitude	*4,000*	*4,000*		
Temperature	*0*	*0*		
Calibrated air speed	*86*	*86*		
Indicated air speed	*91*	*91*		
Direction of relative motion				
Speed of relative motion				
Drift	*20 R*	*10 L*		
Course				
Track				
Ground speed				
Miles on course or track				
Minutes on leg				
Departure time				

FIGURE 57.—Solution for the wind by the double drift method.

absolutely accurate, but generally, instead of a point, the intersections will form a small triangle. Point *E* is then assumed to be the center of the triangle.

PROBLEMS

40. A pilot heads *163°* at a true air speed of *110* knots. *32* minutes later a town is passed over *56* miles *152°* from the starting point. What is the direction and force of the wind, drift angle, track, ground speed?

Working time *5* minutes.

41. Variation *4°* E. A pilot leaves Pensacola at *0935* at a pressure altitude of *7,000* feet. Strut thermometer reads *5°* C., compass reads *015°*. Air speed meter reads *115* knots. At *0957* a point is passed bearing *008°*, *34* miles from Pensacola. What is the direction and force of the wind, drift angle, track, ground speed?

Working time *8* minutes.

42. On heading *020°* the drift angle is *8°* L. On heading *280°* the drift angle is *2°* L. True air speed for both observations *80* knots. What is the direction and force of the wind?

Working time *4* minutes.

43. Variation *15°* E. Pressure altitude *4,500* feet. Temperature *0°* C. Indicated air speed *110* knots. First drift sight: Compass heading *032°*, drift angle *8°* R. Second drift sight: Compass heading *120°*, drift angle *6°* L. What is the direction and force of the wind?

Working time *6* minutes.

44. A pilot takes departure from Pensacola for Montgomery steering a true heading of *025°*. Five minutes later the true bearing of the point of departure is observed *203°*. What is the drift angle? What is the proper heading to steer in order to reach Montgomery which bears *020°* from Pensacola?

Working time *2* minutes.

RELATIVE MOTION

Whenever two objects are moving so that they will both arrive at the same point at the same time, each is said to be on a *collision course* with the other, and the bearing between the two will remain the same until they collide. Consider Ship *A* steaming at 12 knots, headed for a point *X* and 24 miles away from it at *1000*. See figure 58. Ship *B* is also headed for point *X* and is 12 miles away from it at *1000*, steaming at 6 knots. At *1000* the bearing between the two will be the direction of the line *AB*. At *1100* each occupies the position shown, and the bearing line *AB* lies in exactly the same direction as before. In other words, the bearing has remained constant. As the ships continue their course and speed, they will maintain a constant bearing until they meet at point *X*. It is important to notice that neither ship has been headed at the other. *B*, for instance, always appears on the starboard bow of *A*. To an observer on *A* it appears that *B* has always been on the line *AB* which moves along with *A*, so it may be assumed that relative to *A*, *B* has closed the distance on the relative motion line *AB* until a collision occurs. (See fig. 59.)

In the same manner it can be shown that when two objects leave the same point at the same time, a constant bearing will be maintained between the two as the distance opens. Thus, *AB* at *1300* appears as the bearing line or line of relative motion and always lies in the same direction as the ships open the distance. Note that while each ship is going away from the other, neither is directly behind the other.

Observe another important fact with reference to collision courses. If the distance between two such objects is known and the rate of closing of the distance is known, the time it will take to close the distance and arrive at the point of collision can be readily determined.

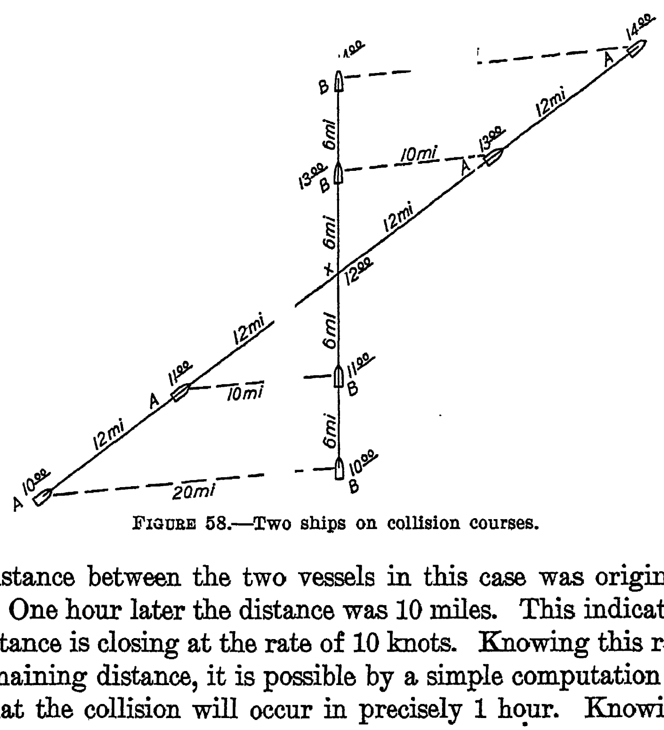


FIGURE 58.—Two ships on collision courses.

The distance between the two vessels in this case was originally 20 miles. One hour later the distance was 10 miles. This indicated that the distance is closing at the rate of 10 knots. Knowing this rate and the remaining distance, it is possible by a simple computation to predict that the collision will occur in precisely 1 hour. Knowing this

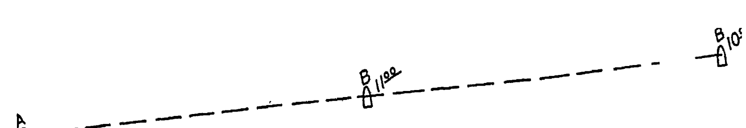


FIGURE 59.—Motion of a ship along a relative motion line.

time, and the speed of each ship, it is also possible to compute how far each ship will have to travel to the point of collision.

Note that while the original distance between the two ships was 20 miles, neither ship had to travel 20 miles to meet the other, and

while the distance between the two is closing at the rate of 10 knots neither ship is traveling at this speed.

The same considerations regarding collision courses and constant bearings that hold true in the case of ships, hold true in the case of any two objects in straight and steady motion. When a pilot is directed to scout on a given relative bearing from the ship as required by tactical considerations, instead of a certain course over the ground, a constant bearing must be maintained. Furthermore, when returning to the ship, return must be made to a moving point instead of to a fixed point and a collision course with the ship must be made good. The course which maintains a constant bearing back to the ship is the shortest path back to the ship.

Consider 1 hour's motion of the wind, ship and aircraft. Assume that with a north wind, the aircraft is headed to make good a course

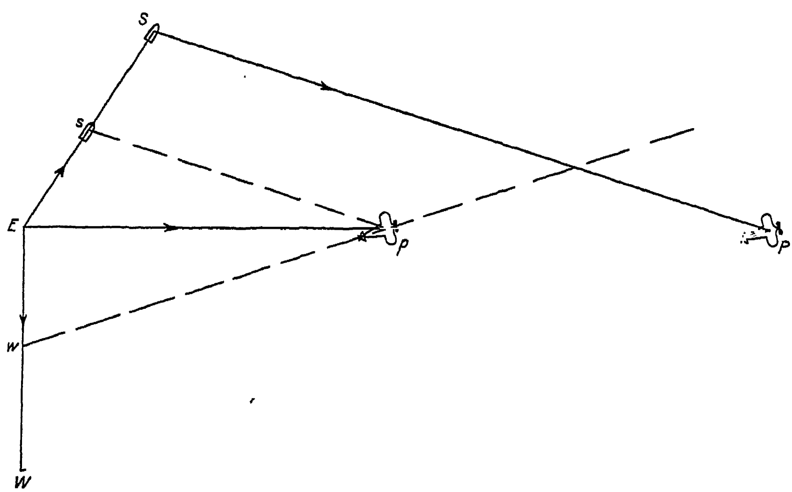


FIGURE 60.—Motion of an aircraft relative to a ship.

of east and the ship is traveling northeast. All motion starts from point E, as shown in figure 60.

In one half hour the aircraft will travel half way out on its heading line, but this line *WP* will move with the wind halfway to *WP*. Meantime, the ship will move half way to *S* and the ship and aircraft in the positions shown, will have the bearing line *sp* between them. At the end of 1 hour the ship will have traveled over the line *ES*, the plane will have traveled over the line *EP* and the bearing line *SP* between them will lie in the same direction as *sp*.

Figure 60 is a speed diagram for wind, ship, and aircraft and by constructing a similar diagram one can find the heading for the aircraft to fly to make good any required bearing from the ship.

It will be noted that the *EPW* triangle is similar to the diagram shown in figure 54 and that the *EPS* triangle is similar to that showing two ships leaving the same point, in figure 58. Now draw and label the speed diagram in the conventional manner, as in figure 61.

It can be seen that the heading, course, and direction of relative motion all lie in the same *general* direction. This diagram is of the greatest importance and should be committed to memory.

EW is direction and force of the wind.

EP is course and ground speed.

WP is heading and air speed.

ES is course and speed of the ship.

SP is direction and speed of relative motion.

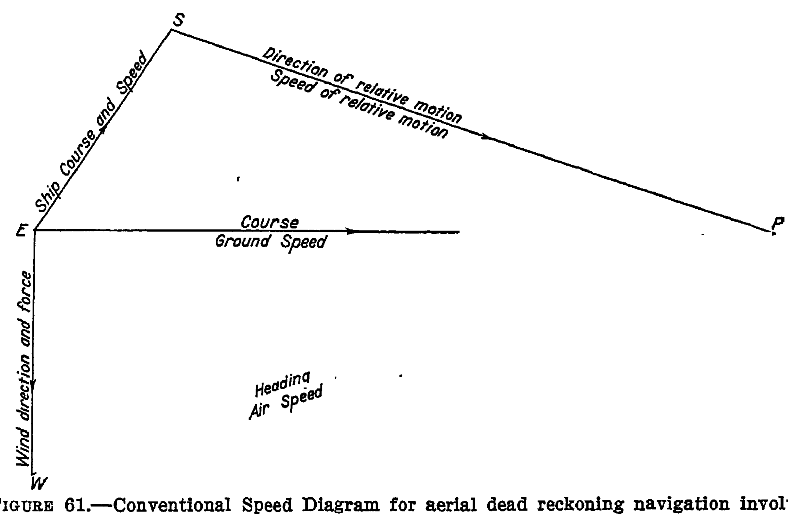


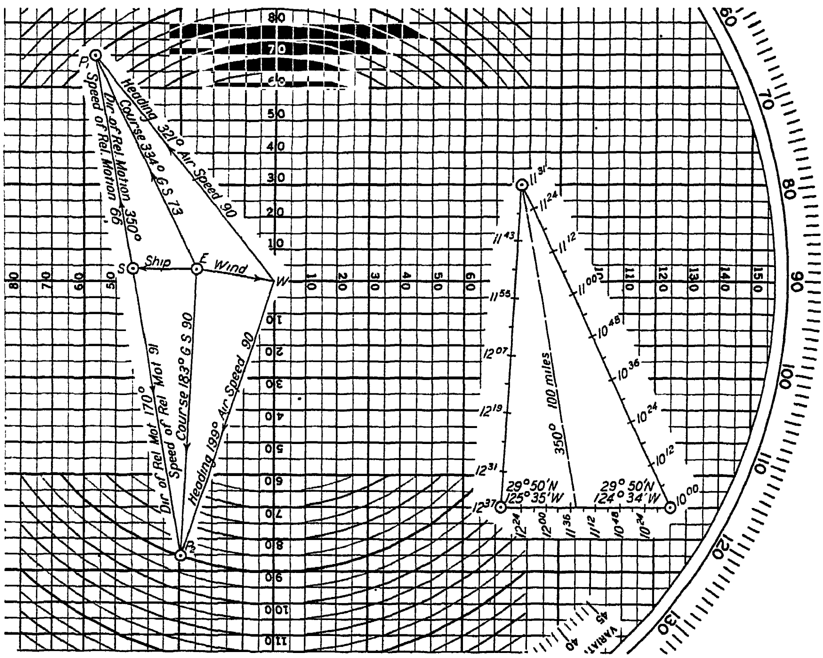
FIGURE 61.—Conventional Speed Diagram for aerial dead reckoning navigation involving motion of a ship.

Assume a typical out-and-in search problem, which involves maintaining a bearing from the ship out and back. An example is stated as follows:

Variation is 16° E. Ship is on course 270°, speed 20 knots. Leaving the ship at *1000*, in lat. 29°50′ N., long. 124°34′ W., scout 100 miles on a bearing of 350° and return to the ship. Use a true air speed of 90 knots and fly at 3,000 feet.

This problem involves two legs. The first leg must take the aircraft to a point where it will be 100 miles from the ship (*not from the starting point*) and will bear 350° from the ship (*not from the starting point*). The second leg merely requires that the aircraft make good such a course that it will intercept the ship, in other words maintain a collision course, or constant bearing.

Along with other information, enter in the log sheet direction of relative motion *350°*, miles of relative motion *100*. Then go ahead



Wind	From	Force	Ship movement			
			Time	Course	Speed	Miles
Surface	*226*	*16*				
1,000	*240*	*18*	*1000*	*270*	*20*	*52*
2,000	*258*	*20*				
3,000	*280*	*25*				
4,000	*317*	*28*				
5,000	*005*	*39*				

Log	Variation: *16° E.*			
	1st leg	2d leg	3d leg	4th leg
Compass heading	*304*	*182*		
Magnetic heading	*305*	*183*		
True heading	*321*	*199*		
True air speed	*90*	*90*		
Pressure altitude	*3,000*	*3,000*		
Temperature	*+10*	*+10*		
Calibrated air speed	*86*	*86*		
Indicated air speed	*91*	*91*		
Direction of relative motion	*350*	*170*		
Speed of relative motion	*66*	*91*		
Miles of relative motion	*100*	*100*		
Course	*334*	*183*		
Ground speed	*73*	*90*		
Miles on course	*111*	*99*		
Minutes on leg	*91*	*66*		
Departure time	*1000*	*1131*	*1237*	

FIGURE 62.—Solution of a relative motion problem.

with the speed diagram, drawing first the wind line to the center of the board as shown in figure 62. Next, the line ES is drawn to represent the ship's course and speed. Then the line SP_1 is drawn from S in the direction of the required relative motion *to the 90 knot air speed circle.* Measure this line and find that speed of relative motion is 66 knots. This means that the aircraft will open the distance between aircraft and ship at the rate of 66 miles per hour. Enter this value in the log sheet. Since it is known that the aircraft must open the distance to 100 miles and that its rate of opening is 66 knots, from the Mk. VIII computer it is found that it will take 91 minutes to complete the first leg. This value is entered as "minutes on leg."

Returning to the speed diagram, draw WP_1 and find that the true heading is 321°. Draw and measure EP_1 and find that the course will be 334° and the ground speed 73 knots. Enter these values in the log sheet and determine from the Mk. VIII computer the number of miles the aircraft will travel on its course in the 91 minutes already determined.

With the grid set up parallel to the course, draw a line from lat. 29°50′ N., long. 124°34′ W., to start the geographic plot of the aircraft's motion. Strike off time intervals as shown and do the same for the ship. There is a very accurate check of the work, because at the end of the first leg at 1131 the aircraft bears exactly 350° from the 1131 position of the ship and has opened the distance to exactly 100 miles.

At this point it will help the student if he will imagine that he has carried a tape measure, the end of which has been kept aboard ship. He has reeled out 100 miles of tape. Obviously, to get back to the ship he has to reel in 100 miles of tape. If he can find the proper heading to maintain the existing bearing as he reels in the tape, and how fast the tape will be reeled in, he can predict just exactly when he should have it all reeled in and consequently be back over the ship.

To return to the ship on the second leg it is necessary to close the distance 100 miles and maintain the same bearing that now exists. Since the motion is now toward the ship instead of away from it, the direction of relative motion is in exactly the opposite direction or 170°, which can be entered in the log sheet and used in drawing SP_2 in the second speed diagram. The length of SP_2 shows the speed of relative motion to be 91 knots. A simple computation then determines that it will take 66 minutes on the second leg to close 100 miles. Similar to the first leg, WP_2 and EP_2 are drawn and measured and the geographic plot is then completed. This affords another accurate check because it is found that the ship and aircraft both reach lat.

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29°50′ N., long. 125°35′ W., at exactly the same time. In the meantime, have the estimated position of the ship and aircraft advanced for time intervals so that the position of the aircraft with reference to the ship is known at all times. Latitude and longitude lines are omitted from the illustration for clarity.

The student should become thoroughly familiar with this type of problem, for while it is little used as a form of search, the principle of the second leg, an interception of a moving ship, must be utilized in all other forms of search from a ship when the pilot computes the returning leg. It might be stated at this point that each leg of any scouting problem boils down to just one of two things—motion along a required *course* between two geographic points, or motion in a required *direction* relative to a moving ship.

PROBLEMS

45. A pilot is *87* miles from the ship and closing the distance at the rate of *96* knots. How long will it take to reach the ship? If a ground speed of *102* knots is made how far will the aircraft travel on its course?

Working time *2* minutes.

46. A pilot scouts *120* miles on a course of *030°* and returns to the ship, using a true air speed of *140* knots at *1,000* feet. Ship's course *035°*, speed *30* knots, variation *12°* E. Find compass heading, minutes on each leg.

Working time *9* minutes.

47. A utility airplane leaves North Island to intercept a ship bearing *290°*, distant *50* miles, at an air speed of *85* knots. Altitude *5,000* feet. Find true heading and time until interception. Ship: Course *010°*, speed *20* knots.

Working time *3* minutes.

48. A cruiser airplane is directed to scout out *75* miles on a bearing of *120°* and return, at an altitude of *1,000* feet, true air speed of *105* knots. The airplane leaves the ship at *1620*, in lat. *31°20′* N., long. *125°11′* W. Ship's course *200°*, speed *24* knots. Variation *16°* E. Temperature plus *10°* C. Find compass heading and indicated air speed out and back, time to turn, latitude, and longitude of interception of ship.

Working time *15* minutes.

49. Variation *16°* E. Ship's course *330°*, speed *22* knots. A pilot leaves the ship as a wing man and records the following data:

Time	Compass heading	Indicated air speed	Altitude	Temperature
0932	*310°*	*112* knots	*4000*	plus *5°* C.
0949	*263°*	*112* knots	*4000*	plus *5°* C.

At *1102* orders received to return to ship. What compass heading should be steered to return at the maximum air speed of *140* knots? What time should the plane arrive?

Working time *12* minutes.

50. The pilot is in No. *3* plane following the section leader and the following data is logged after the ship is left at *1020:*

Watch Time	Compass heading	Air speed indicator	Pressure altitude	Temperature
1020	*310°*	*109* knots	*3,000* feet	*0°* C.
1040	*005°*	*109* knots	*3,000* feet	*0°* C.

Ship: course *355°*, speed *18* knots. Variation *15°* E. At *1130* the section leader is forced down. What is the leader's bearing and distance from the ship? What compass heading must the pilot of No. 3 steer to return to the ship at a true air speed of *120* knots, if the ship continues course and speed? At what time should the ship be intercepted?

Working time *20* minutes.

51. A pilot is instructed to scout *80* miles on a course of *090°* and return to the ship, using true air speed *100* knots, at an altitude of *1,000* feet. Ship on course *110°*, speed of *28* knots; *5* minutes after leaving the ship a sight on the ship's Pelorus reveals that the plane bears *080°*. Is the pilot making good the required course? When on the returning leg, will the pilot be likely to pass ahead or astern of the ship?

Working time *5* minutes.

52. A cruiser pilot is directed to take departure from the ship at *1000*. Departure is made at *1000* by the pilot's watch, which is *5* minutes fast and he proceeds on the first leg, opening the distance at the rate of *120* knots. Ship receives a message at *1030* that the pilot's airplane is making a forced landing. The navigator computes the location of the airplane preparatory to rescue operations. How far is the airplane from the position computed by the navigator?

Working time *3* minutes.

53. At *0900* a carrier on course *020°*, speed *30* knots, is *150* miles northwest of San Diego. An airplane leaves San Diego at *1030* to join the carrier. At an air speed of *110* knots, at *4000* feet: What is the heading to interception? What time does the airplane arrive at carrier?

Working time *12* minutes.

54. An airplane is ordered to leave the entrance of Pensacola Bay and intercept a ship which left Mobile Point Light at *0800* on course *165°*, speed *25* knots. Mobile Point Light bears *258°*, *39.5* nautical miles from Pensacola Bay entrance. True air speed of airplane is *125* knots. Variation *4°* E. The pilot leaves the entrance to Pensacola Bay at *0900* to intercept the ship. Pressure altitude *5,000* feet. Temperature plus *20°* C. What is compass heading? What is the time of interception?

Working time *8* minutes.

55. Base *B* is *70* miles south of base *A*. At *0800* a ship leaves base *B* on course *110°*, speed *20* knots. An airplane leaves base *A* at the same time to intercept the ship, air speed *70* knots, at *2,000* feet. What is the heading of the airplane? At *0840* the ship radios the airplane that the course and speed of the ship is being changed to east at *25* knots. What is the airplane's new heading and at what time does it reach the ship?

Working time *12* minutes.

56. A pilot is catapulted from a cruiser at *1015*. While waiting for the second airplane to be catapulted the pilot estimates from the streaks on the water that the wind is *18* knots from *070°*. The two airplanes start to scout on a course of *058°* at *1020* for *80* miles and return. The cruiser continues on course *238°*, speed *25* knots. The airplanes fly at *85 knots*. At what time should they turn back?

Working time *7* minutes.

57. At *0800*, ship in lat. *37°48′* N., long. *74°38′* W., course *172°*, speed *12* knots. At *0900* plane departs from ship and proceeds to Norfolk to pick up mail. Position of Norfolk lat. *36°50′* N., long. *76°18′* W. At most favorable altitude the temperature is *+5°* C. True air speed *120* knots. Variation *6°* W. Plane remains at Norfolk for *30* minutes. Return flight is made at most favorable altitude, same temperature. What is estimated time of arrival over ship? What is the position of the ship at time of interception?

Working time *30* minutes.

58. In foul weather, a radio bearing of *125°* of the ship is obtained. From the surface of the water the pilot estimates the wind at *12* knots from *300°*. Ship's course and speed *22* knots, *300°*. What heading of plane is steered at air speed *110* knots true to intercept the ship?

Working time *4* minutes.

59. A pilot is ordered to scout at *100* knots true air speed, altitude *5,000* feet on a bearing of *360°* from the ship to a distance of *80* miles and return to the ship. When departure is taken from the ship, the position is lat. *30°30′* N., long. *116°20′* W.; *10* minutes later the ship disappears from view. What is the visibility? Ship's course *076°*, speed *15* knots; *30* minutes after the ship is left, another ship bearing *015°* *8* miles away is sighted. What is the bearing and distance of this latter ship from your ship? What is the latitude and longitude of the ship sighted? What true heading is steered on the returning leg? In what latitude and longitude should you arrive over your ship?

Working time *30* minutes.

60. A pilot is directed to scout out *90* miles on a course of *170°* and return to the ship, using a true air speed of *95* knots, at an altitude of *1,000* feet. Temperature *0°* C. Ship's course and speed *200°*, *25* knots. Variation *12°* E. The ship is left at *1027*. At*1114* the objective vessel is sighted, bearing *160°*; *10* miles away. Remain in the vicinity, and report the objective vessel's course as *215°*, with speed of *20* knots and send further reports. At *1152* objective changes course to *285°*. At *1230* the plane is *6* miles astern of the objective and wishes to return to its ship. What is the heading?

Working time *15* minutes.

61. The position of the carrier at *0800* is lat. *37°20′* N., long. *127°35′* W., and the position of objective at *0800* is lat. *35°10′* N., long. *128°10′* W. The carrier's course is *285°*, speed *24* knots. Objective's course *275°*, speed *30* knots. At *0840* depart from carrier at a true air speed of *140* knots, altitude *5,000* feet, variation *16°* E., temperature plus *15°* C., to rendezvous over the objective. Find the compass heading, the indicated air speed, and the time of the rendezvous. Assume that the objective is not located due to a change of course or poor visibility. Find the compass heading and the time of the return to the carrier.

Working time *30* minutes.

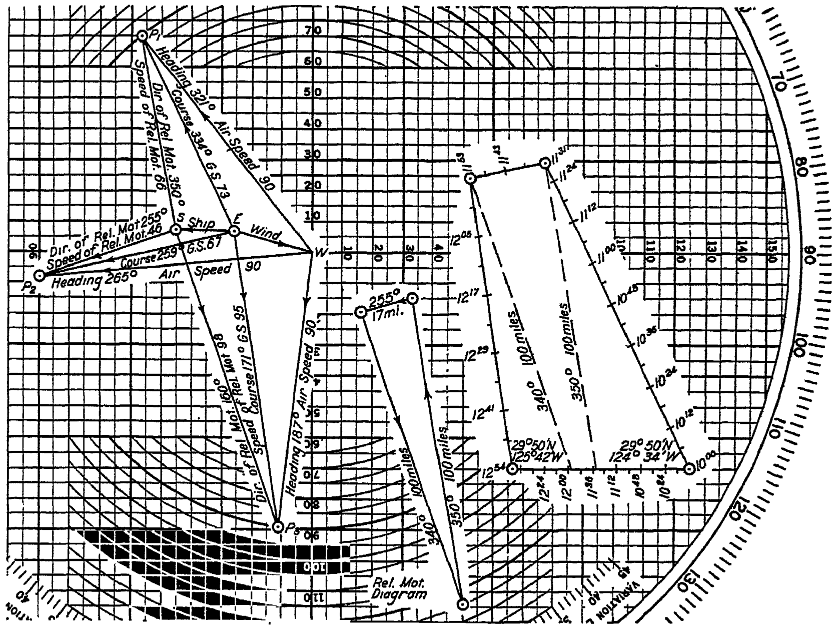
RELATIVE AND GEOGRAPHIC SECTOR

A problem often assigned is a *sector* search, originating at a designated point and extending over an area limited by the designated radii and assigned distance.

In a *relative sector* the designated point is a moving ship and relative motion is involved. The usual procedure is to depart on rear limiting bearing to the distance required, then to change course to cover the base of the triangle, and return directly from the extremity of the second leg. The third leg of the flight is thus an interception and will not necessarily coincide with the radius of the sector.

Example.—Variation *16°* E. Ship's course *270°*, speed *20* knots. Leaving the ship at *1000*, in lat. *29°50′* N., long. *124°34′* W., search a *100*-mile relative sector from a bearing of *350°* to a bearing of *340°* and return to the ship. Use a true air speed of *90* knots and fly at *3,000* feet.

First draw a relative motion diagram in any convenient part of the board as shown in figure 63. This will show the motion of the plane with relation to the ship, *100* miles out on a bearing of *350°*, *100* miles back on a bearing of *340°* with a middle leg connecting the first and



Wind	From	Force	Ship movement			
			Time	Course	Speed	Miles
Surface	226	16	1000	270	20	58
1,000	240	18				
2,000	258	20				
3,000	280	25				
4,000	317	28				
5,000	005	39				

Log	Variation: 16° E.			
	1st leg	2d leg	3d leg	4th leg
Compass heading	304	246	170	
Magnetic heading	305	249	171	
True heading	321	265	187	
True air speed	90	90	90	
Pressure altitude	3,000	3,000	3,000	
Temperature	+10	+10	+10	
Calibrated air speed	86	86	86	
Indicated air speed	91	91	91	
Direction of relative motion	350	255	160	
Speed of relative motion	66	46	98	
Miles of relative motion	100	17	100	
Course	334	259	171	
Ground speed	73	67	95	
Miles on course	111	25	97	
Minutes on leg	91	22	61	
Departure time	1000	1131	1153	1254

FIGURE 63.—Solution of a relative sector problem.

last which is *17* miles in a direction of *255°*. This pattern moves along with the ship.

The first leg will be precisely the same as the first leg of the previous example (fig. 62) and will give exactly the same geographic plot. The second leg requires the pilot to fly to a point that will bear 340° from the ship's position at that time and that will be 100 miles distant from the ship. The direction and miles of relative motion are found from the relative-motion diagram. This permits making the proper entries in the log sheet, and a speed diagram can be constructed for the second leg as shown. When the geographic diagram is completed up to this point, it shows the airplane does bear 340° from the ship and the distance is 100 miles, and proves that the requirements of the problem have been met. The returning leg is handled the same way as in the previous problem, the direction of relative motion in this case being exactly opposite to 340°, or 160°. When the geographic plot is completed it shows that the airplane intercepted the ship at 1254, which was the time previously computed for the end of the third leg.

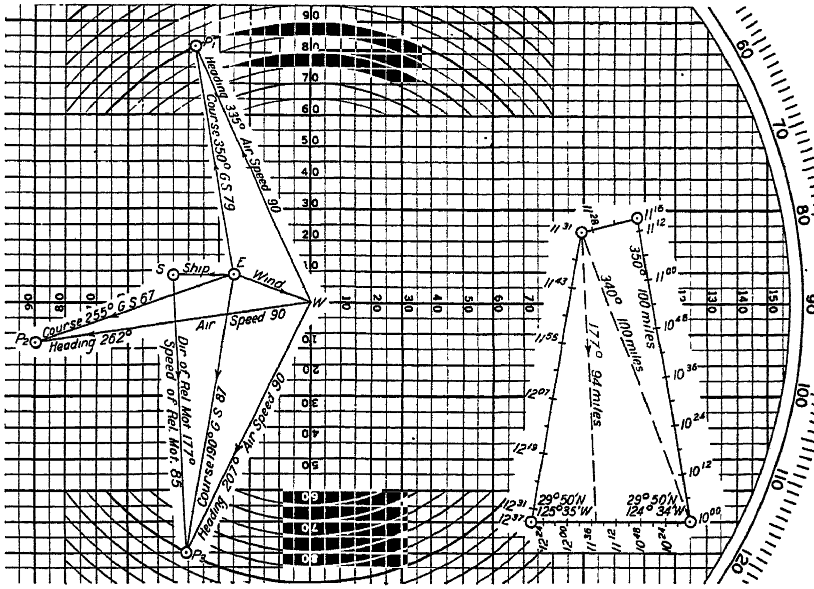
It should be noted that the direction of relative motion for the second leg is 90° to the median line of the sector, in a direction approximately the same as the ship's course.

In a geographic sector the origin is a fixed geographical point, and all bearings and distances are measured from this point.

Example.—Variation 16° E. Ship's course *270°*, speed *20* knots. Leaving the ship at *1000* in lat. *29°50′* N., long. *124°34′* W., scout a *100*-mile geographic sector from *350°* to *340°* and return to the ship. Use a true air speed of *90* knots and fly at *3,000* feet.

The solution of this problem is shown in figure 64. The first leg requires that the pilot make good *100* miles on a course of *350°*. A simple speed diagram gives the pertinent data on the first leg. The first leg in the geographic plot is then drawn. The next leg requires arrival at a point *100* miles from the starting point, bearing *340°* from it, and after plotting in this point in the geographic plot, it determines a required travel of *17* miles on a course of *255°*. A second speed diagram gives additional data on this leg.

The third leg in this case is an interception of the ship and to find the direction and miles of relative motion to make good, refer to the positions of the airplane and ship at the end of the second leg. This indicates that the airplane must close the distance of *94* miles on a bearing of *177°*. A speed diagram for the third leg involving motion relative to the ship, gives the data necessary to complete the problem. The geographic plot shows that the ship and airplane again arrive at the same place at the same time, thus giving a good indication that the work was done correctly.



Wind	From	Force	Ship movement Time	Course	Speed	Miles
Surface	226	16	1000	270	20	30
1,000	240	18	1131	270	20	22
2,000	258	20				
3,000	280	25				
4,000	317	28				
5,000	005	39				

Log	Variation: 16° E. 1st leg	2d leg	3d leg	4th leg
Compass heading	319	243	190	
Magnetic heading	319	246	191	
True heading	335	262	207	
True air speed	90	90	90	
Pressure altitude	3,000	3,000	3,000	
Temperature	+10	+10	+10	
Calibrated air speed	86	86	86	
Indicated air speed	91	91	91	
Direction of relative motion			177	
Speed of relative motion			85	
Miles of relative motion			94	
Course	350	255	190	
Ground speed	79	67	87	
Miles on course	100	17	96	
Minutes on leg	76	15	66	
Departure time	1000	1116	1131	1237

FIGURE 64.—Solution of a geographic sector problem.

PROBLEMS

62. Ship's course *050°*, speed *20* knots. Search *75*-mile relative sector from *120°* to *100°* at a true air speed of *95* knots, at an altitude of *5,000* feet. Required: True heading and time on each leg.

Working time *12* minutes.

63. Patrol a *40*-mile relative sector from *1310* until further orders with limiting bearings of *320°* and *340°*, at altitude *3,000* feet, true air speed *90* knots. Temperature plus *20°* C. Variation *6°* E., ship's course *065°*, speed *27* knots. Find compass heading, indicated air speed and time for each leg. If the ship is left in lat. *32°16'* N., long. *121°18'* W. and the pilot recalled at *1600*, what will be the position of the ship at time of interception?

Working time *20* minutes.

64. Ship's *0800* position, Lat. *33°40'* N., Long. *122°22'* W., course *212°*, speed *22* knots. Variation *15°* E. A pilot is directed to leave the ship at *0910* and scout a *90*-mile geographic sector from *300°* to *285°* and return to the ship. Fly at *105* knots, at an altitude of *2,000* feet. Temperature plus *25°* C. Find time of each turn, heading for each leg. At *1018* a disabled ship is sighted *8* miles away and bearing *290°*. Report disabled ship's latitude and longitude. In what position should contact be made with your ship?

Working time *30* minutes.

VARIATIONS OF THE BASIC PROBLEM

It is sometimes necessary to ascertain the greatest distance an aircraft can travel in a given direction from its ship or base, under given conditions of wind, true air sped and ship's motion, if any, and return to its destination within the time limitations imposed by fuel capacity or daylight. This distance is called the *radius of action* although it applies only in the direction under consideration and not in all directions.

It can be shown that a proportion exists between similar distances and similar time intervals in problems having a similar pattern. For example, assume plane *A* flies away from the ship for 1 hour on a given bearing. Plane *B* flies out on the same bearing at the same air speed for 2 hours. Then *B* will travel twice as far on its bearing and twice as far on its track as *A* and will take twice as long to complete its returning leg. It follows that the total time for the flight will be twice as long for *B* as for *A*, and the pattern of each flight will be similiar.

Thus, a proportion is established which can be used to find the maximum travel on the first leg when expressed as follows:

$$\frac{\text{Total minutes on sample problem}}{\text{Miles on 1st leg of sample problem}} = \frac{\text{maximum total minutes}}{\text{maximum miles on 1st leg}}$$

This proportion can be remembered easily and is quickly solved on the Mk. VIII computer. It will hold good for out-and-in search or sector search.

For example, refer to the problem illustrated in figure 62. It will be seen that it took a total of *157* minutes to scout *100* miles from the ship and return to it. To find how far it would have been possible to scout and return in 4 hours, solve this proportion on the Mk. VIII computer:

$$\frac{157 \text{ minutes}}{100 \text{ miles}}=\frac{240 \text{ minutes}}{x \text{ miles}}$$

and find that $x=153$ miles.

An alternate method of solution is provided by the following formula:

$$t \quad \frac{T\times S_2}{S_1+S_2}$$

where

t=minutes on first leg;

T=total minutes available for flight out and back;

S_1=relative motion rate out or ground speed out;

S_2=relative motion rate back or ground speed back.

This formula can likewise be solved on the Mk. VIII computer by setting up a proportion as follows:

$$\frac{S_1+S_2}{S_2}=\frac{T}{t}$$

Thus, referring to the problem illustrated in figure 62, it will be seen that the above formula is expressed with these values to find when to turn back so as to arrive in 4 hours:

$$\frac{66+91}{91}=\frac{240}{t}$$

Solving on the Mk. VIII computer,

$$\frac{157}{91}=\frac{240}{t} \text{ and, } t=139 \textit{ minutes}$$

This method is adaptable to only out-and-in problems, and will not serve for sectors. If the motion is out on a given course, and back along the same course, ground speeds may be substituted in the formula for relative motion rates.

Use of a "fictitious" ship with special problems.—Problems of certain types can be solved only if an imaginary ship, properly related to the problem, is supposed to exist. For example:

With wind and air speed given in figure 62, scout from base A as far as possible on course 334° and return to base B, 80 miles west of A, in 4 hours. Assume that the aircraft is operating from a fictitious ship which will leave A and arrive at B 4 hours later. The course of this ship would thus be determined as 270°, its speed as 20 knots. With this assumption, the problem becomes a radius of action problem. Therefore, find the time necessary to scout any arbitrary number of miles on course 334° and return to the moving ship. Using the value of 111 miles as shown in figure 62, the corresponding time is 157 min-

utes. Solving the appropriate proportion for the maximum time of 240 minutes, the maximum miles on course is found to be 169.

Estimated force and direction of wind between recorded levels.—The aerologist furnishes the force and direction of the wind for each 1,000-foot level. To fly at an intermediate level, between two wind values that differ only a little, a pilot should use the average of the two.

If there is a marked difference between the wind force or direction at two successive recorded altitudes, there is likely to be turbulent air at some point between. If, while climbing, for example, to 2,500 feet, rough air is encountered, it is very likely that the aircraft is passing through the wind shift level, and the wind for 3,000 feet should be used. If rough air is not encountered, the wind for 2,000 feet should be used.

Indicated altitude, corrected altitude and pressure altitude.—Corrected altitude is the value that must be used when selecting the proper wind from the wind table. At low altitudes with an accurate instrument, this may be assumed to be the indicated altitude, providing the altimeter has been set at take-off to read the altitude above sea level of the point of departure. At high altitudes, this assumption will not be a close approximation, and therefore the indicated altitude will have to be converted to corrected altitude on the Mk. VIII computer to avoid the error of flying at one level while using the wind for an entirely different level.

Pressure altitude is only an index of the air density at the level of the aircraft and is the value that must be used in entering the Mk. VIII computer to correct air speed and altitude. It will generally differ from both the indicated altitude and corrected altitude and must not be used for entering the wind table.

PROBLEMS

65. Refer to figure 63. What is the maximum distance that could be searched in this sector in *4½* hours? Same for figure 64.

Working time *6* minutes.

66. Refer to problem 48. How far could the aircraft scout from the ship and return if there were *4* hours of daylight?

Working time *18* minutes.

67. Refer to problem 46. How far could aircraft scout on the track and return in *2* hours?

Working time *12* minutes.

68. Scouting Squadron Three departs Point Loma at *0917* to proceed as far as possible on course *234°* and return at the end of *3* hours. Air speed *110* knots, altitude *4,000* feet. Required: (1) Time to turn; (2) ground speed out; (3) ground speed back.

Working time *6* minutes.

69. A ship leaves New York at *0430* at *28* knots, on a course of *098°*. A coast guard pilot is instructed to accompany the ship as far as possible, returning to New York at a true air speed of *100* knots, to arrive at *1000*. Find all

essential information for this operation to be conducted at *4,000* feet, temperature *—10° C.*

Working time *10* minutes.

70. Fighting Squadron Three is ordered to proceed on bearing *137°* from *Saratoga* as far as possible and return at the end of *3* hours. *Saratoga* course *000°*, speed *25* knots. Air speed *110* knots. Variation *15°* E., altitude *1,000* feet. Required: (1) Compass headings out and back; (2) courses out and back; (3) time to turn.

Working time *10* minutes.

71. You are ordered to leave Long Beach, Calif., and scout at *1,000* feet as far west as possible returning to North Island at the end of 4 hours. North Island is *110* nautical miles from Long Beach. Air speed *130* knots. Leaving Long Beach at *0800* what time do you turn? What is your heading on last leg? North Island bears *165°* from Long Beach.

Working time *10* minutes.

72. Bombing Squadron Three is ordered to proceed to Point Baker bearing *125°*, distant *70* miles from the point of departure, then scout on course *050°* as far as possible and return to the *Saratoga* at the end of *3.5* hours from time of take-off. *Saratoga* course *050°*, speed *30* knots. Air speed *110* knots. Altitude *4,000* feet, temperature *0°* C. Time of departure *0800*. Variation *15°* E. Required: (1) true heading to Point Baker; (2) time of arrival at Point Baker; (3) time to turn; (4) compass heading back to ship.

Working time *30* minutes.

73. Ship's course *260°*, speed *20* knots. You leave the ship at *0800* to scout on a course of *180°* at a true air speed of *100* knots at an altitude of *2,000* feet. At *0930* you contact objective on a course of *280°*, speed *20* knots. How long can you remain in the vicinity of objective and return to your ship by *1200*?

Working time *20* minutes.

74. Point Affirm is in lat. *37°25′* N., long. *136°30′* W. At *0800* with the ship steaming on course *016°*, speed *27* knots, Point Affirm bears *086°*, distant *92* miles. Using a cruising speed of *120* knots at *4,000* feet, rendezvous at Point Affirm with another squadron at *1000*. What time should you leave the ship?

Working time *18* minutes.

75. A pilot intends to fly at *2,500* feet from Pensacola to Jackson, which bears *305°*. Using a true air speed of *120* knots what should be his true heading?

Working time *5* minutes.

76. An air group at an indicated altitude of *18,500* feet, temperature *–13°* C. is ordered by radio to intercept objective vessel bearing *255°*, distant *135* miles at a true air speed of *150* knots. The objective is on course *360°*, speed *20*. Find heading and time until interception. Pressure altitude *18,000* feet.

Wind	*From*	*Force*
17,000	*025°*	*45*
18,000	*075°*	*50*
19,000	*100°*	*55*

Working time *8* minutes.

77. At *0918* the position of *Saratoga* is lat. *32°39′* N., long. *117°47′* W., at which time squadron takes departure for Point Zed which is at lat. *34°02′* N., long. *119°11′* W. *Saratoga* course *096°*, speed *20* knots. Air speed *110* knots. Variation *15°* E., *altitude 5000* feet. Temperature *5°* C. *Use midlatitude 33°*

for plotting. Required: (1) Compass heading to Point Zed; (2) time of arrival at Point Zed; (3) indicated air speed.

78. Biloxi, Miss., is *96* nautical miles bearing *271°* from Pensacola. An airplane, air speed *95* knots, leaves Biloxi at *3,000* feet on course *140°*. At the same time an airplane, air speed *100* knots, leaves Pensacola to intercept it, at *3,000* feet. What is the time to interception? What is the heading true to interception?

Working time *5* minutes.

79. Variation *16°* E. Ship on course *335°*, speed *21* knots. At *1220* a section leaves the ship with orders to scout *80* miles on a bearing of *035°* at a true air speed of *110* knots, at an altitude of *4,000* feet. A wing man logs the following data:

	First leg	*Second leg*
Watch time.	*1220.*	*1320.*
Compass heading.	*359°.*	*220°.*
Air speed indicator.	*111* knots.	*108* knots.
Altitude.	*4,000* feet.	*4,000* feet.
Temperature.	plus *5°* C.	plus *5°* C.

At the time the section leader expects to be over the ship, what is the probable bearing and distance of the ship?

Working time *15* minutes.

ANSWERS

1. Calibrated air speed *105* knots.
2. Indicated air speed *124* knots.
3. True air speed *111* knots.
4. Indicated air speed *115* knots.
5. Minutes on leg *47*.
6. Time to turn *1411*.
7. Miles on leg *164*.
8. Ground speed *79½* knots.
9. *51* minutes. *118½* miles.
10. Ground speed *151* knots.
11. True heading *000°*.
12. Compass heading *169°*.
13. Bearing *088°*.
14. Course *128°*.
15. Bearing made good *056°*.
16. No.
17. Yes.
18. Middletown.
19. *84* miles.
20. Bearing *095°*, distance *83* miles.
21. *55* miles. *132* miles.
22. Bearing *297°*, distance *44* miles. Lat. *30°44′ N.*, long. *85°14′ W.* Bearing *328°*, distance *56* miles.
23. Bearing *010½°*, distance *132* miles. Bearing *010°*, distance *128* miles.
24. Lat. *38°18′ N.*, long. *145°24′ W.* Bearing *303°*, distance *177* miles.
25. Bearing *135°*, distance *66* miles.
26. Bearing *040°*, distance *171* miles.
27. *162* miles, course *98°*.
28. Bearing *282°*, distance *107* miles. Lat. *35°06′ N.*, long. *114°52′ W.*

29. True heading *246°*. Ground speed *77* knots, wind correction angle *14°* L. No.

30. Compass heading *02*

31.		Going	Returning
	Compass heading	*188°*	*343°*.
	Indicated air speed	*88* knots	*88* knots.
	Minutes on leg	*35*	*35*.
	Head wind	*Yes*	*Yes*.

32.		First leg	Second leg	Third leg
	Depart. time	*1315*	*1351*	*1420*
	Compass heading	*307°*	*234°*	*073°*

Indicated air speed *92* knots.
Time of return *1450*.

33. Compass heading *227°*. Time of arrival *1526*.

34. Compass heading *79°*, indicated air speed *101* knots, time of arrival *1056*.

35. Compass heading *037°*, indicated air speed *102* knots, time of arrival *0934*. Right.

36.		Going	Returning
	True heading	*085°*	*289°*.
	Minutes on leg	*78*	*98*.

37. Compass heading, *111°*, *2* hours *1* minute. Lat. *18°53′ N*., long. *73°02′ W*.

38.		First leg	Second leg
	Compass heading	*164°*	*347°*.
	Ground speed	*121* knots	*100* knots.

Elapsed time, *1* hour *52* minutes.

39.		First leg	Second leg	Third leg
	Compass heading	*269°*	*167°*	*020°*
	Ground speed	*82* knots	*102* knots	*82* knots.

Time of return, *1029*.

40. Wind from *234* , force *21* knots, drift angle *11° L*., track *152°*, ground speed *105* knots.

41. Wind from *040* , force *35* knots, drift angle *9° L*., track *008°*, ground speed *93* knots.

42. Wind from *086°* force *12* knots.

43. Wind from *277°* force *22* knots.

44. Drift angle *2° L*. *023°*.

45. *54½* minutes. *93* miles on course.

46.		First leg	Second leg
	Compass heading	*016°*	*198°*
	Minutes on leg	*46½*	*37½*

47. True heading *332°* minutes on leg *60*.

48.		First leg	Second leg
	Compass heading	*128°*	*259°*.
	Indicated air speed	*109* knots	*109* knots.

Time to turn, *1704*,
Lat. *30°46′ N*., long. *125°26′ W*.

49. Compass heading *057°*. Time of arrival *1142*.

50. Bearing *023°*, distance *95* miles. Compass heading *202°* Time of return *1215*.

51. *No. Astern.*

52. *10* miles.

53. Heading *337°*. Time of interception *1319*.

54. Compass heading *219°*. Time of interception *0919*.
55. Heading *180°*. Heading *176°*, time of interception *0908*.
56. Time of turn *1132*.
57. Time of return *1048½*. *Lat. 37°15′ N.*, Long. *74°32′ W.*
58. Heading *126½°*.
59. Visibility *9½* miles. Bearing *003°*, distance *35* miles. Lat. *31°07′ N.*, long. *116°10′ W.* Heading *170°*. Lat. *30°38′ N.*, long. *115°46′ W.*
60. Compass heading *297°*.
61. Compass heading *198°*, indicated air speed *128* knots, time of rendezvous *0931*. Compass heading *353°*, time of return *1100*.

	First leg	*Second leg*	*Third leg*
62. Heading	*085°*	*020°*	*314°*
Minutes on leg	*51*	*39*	*52*

	First leg	*Second leg*	*Third leg*	*Returning leg*
63. Compass heading	*320°*	*048°*	*151°*	*151°*
Indicated air speed	*88*			
Departure time	*1310*	*1341*	*1351*	*1600*

Lat. *32°53′ N.*, long. *119°42′* W.

	First leg	*Second leg*	*Third leg*
64. Departure time	*0910*	*1010*	*1025*
Compass heading	*277°*	*195°*	*130°*

Lat. *33°55′ N.*, long. *124°21′ W. Lat. 32°40′ N.*, long. *123°02′ W.*

65. *155½ miles. 172* miles.
66. *193* miles.
67. *171* miles.
68. Time to turn *1050;* ground speed out *103* knots; ground speed back *110* knots.
69. Commence returning leg at *0830*, indicated air speed *103* knots, true heading *289°*.
70. Compass heading out *125°*, back *300°*; course out *129°*, back *326°*; time to turn *73* minutes.
71. Time to turn *1000*. Heading *118°*.
72. Time of arrival *0830½*; time to turn *1013;* compass heading *250°*; heading

73. *63* minutes.
74. *0925*.
75. Heading *298½°*.
76. Compass heading *254°*, minutes on leg *39½*.
77. Compass heading *318°*; time of arrival *1040;* indicated air speed *108* knots.
78. Minutes on leg *53*. Heading *217°*.
79. Bearing *240°*, distance *12* miles.

Chapter IV

RADIO NAVIGATION

Radio is assuming an ever increasing importance in aerial navigation as a means of checking a dead reckoning position. However, radio equipment is subject to mechanical failure, and when available requires outside help to obtain bearings, therefore the pilot should not be entirely dependent upon radio navigation. On the other hand situations frequently arise where radio offers a most convenient aid in determining position.

RADIO TIME SIGNALS

The aircraft navigational watch is used to afford an accurate time for celestial observations. This watch, like others, is affected by temperature and other conditions, which will cause it to be in error. It is therefore necessary to determine the error of the watch at intervals in order to establish the rate at which it is gaining or losing time. Radio time signals afford a means of determining these errors by comparing the watch with the exact time of the time tick or signal.

At the present time there is a lack of uniformity in the systems employed for the broadcast of radio time signals. In the United States system, the transmission of signals begins at 55 minutes 0 seconds of some hour, and continues for 5 minutes. Signals are transmitted on every second during that time, except that there is no signal on the 29th second of any minute, or on certain seconds at the ends of the minutes, as shown in the following diagram:

Minute	Second																	
	1–26	27	28	29	30	31	32–49	50	51	52	53	54	55	56	57	58	59	60
55	— —	—	—		—	—	— —	—		—	—	—	—					—
56	— —	—	—		—	—	— —	—	—		—	—	—					—
57	— —	—	—		—	—	— —	—	—	—		—	—					—
58	— —	—	—		—	—	— —	—	—	—	—		—					—
59	— —	—	—		—	—	— —	—										———

The dashes in the above diagram indicate seconds on which signals are transmitted. The seconds marked "60" are the zero seconds of the following minutes. All seconds from 0 to 50, inclusive, are transmitted except the 29th second, as explained above. The dash on the beginning of the hour (shown as 59 minutes 60 seconds above) is much longer than the others (i. e., 1.3 seconds).

In all cases the beginning of the dashes indicate the beginnings of the seconds, and the ends of the dashes are without significance.

It will be noted that the number of dashes sounded in the group at the end of any minute indicates the number of minutes of the signal yet to be sent.

RADIO BEARINGS

Radio bearings are lines of position. They may be used for fixing an aircraft's position in the same manner as other lines of position if due regard is given to the facts that they, like other lines of position, may not be absolutely accurate, and that the bearings are great circle tracks, not rhumb lines.

A technical discussion of the principle of the radio direction-finder is not considered necessary at this point. It will suffice to say that certain antennas are highly directional and the direction from which a signal is coming may be measured.

Suppose you are searching for a treasure and your directions state it is located directly south of a certain water tank and directly west of a certain oak tree. To locate the treasure it is first necessary to locate the water tank and oak tree. Having done this a line is drawn directly south from the water tank and the treasure is somewhere on this line. Also if a line is drawn directly west from the oak tree the treasure is somewhere on this second line. Now, having two lines and knowing the treasure is on both of them the only possible location is where these lines cross. This is exactly the way a pilot fixes his position by radio bearings. For example, a pilot desiring to know his position will transmit a radio signal and ask certain shore stations to determine the direction of the aircraft from these stations. This is done and the stations report the bearing to the pilot. The pilot then, knowing the locations of the stations, plots them on a chart and then draws the bearing lines from the stations. Where these lines cross then is the location of the aircraft. It is customary to use three stations, if available, to insure a more accurate position.

In plotting the above bearings on a mercator projection it is necessary to make a correction to them. This is caused by the fact that ground waves of a radio transmitter follow the shortest distance between any two points on the earth's surface, which is a great circle course. As defined in chapter one, a great circle is a circle on the earth's surface whose plane passes through the center of the earth, or the center of the earth is the center of the circle.

Referring to figure 1, it is seen that the great circle shown there cuts the meridians at different angles. This means then that its direction is constantly changing. Starting at the left it is seen the direction at the 45° meridian is southeast, at the 15° meridian it is practically

east, and then becomes more northerly. This great circle then, when plotted on a mercator chart, would appear as a curved line because the meridians are straight lines. The rhumb line, on the other hand, cuts all meridians at the same angle and is therefore of constant direction. When plotted on a mercator chart the rhumb line then will appear as a straight line.

A radio bearing cannot be plotted as a straight line on a mercator chart except when the difference in longitude of the dead reckoning position and the station is less than 50 miles, in which case no appreciable error will be introduced. However, using the approximate latitude and longitude of the aircraft's position and the latitude and longitude of the radio direction finder station, obtained from Radio Aids to Navigation (H. O. 205) the difference between the initial great circle course and the mercator course from the station will serve as a correction to obtain the rhumb line from the station that will pass through the aircraft's position. The actual radio bearing received from the radio direction finder station will probably not be the same as that computed, for only an approximate position of the aircraft was used in the computation, but the correction may be used through quite wide limits without producing a material error.

In practice it is not necessary to make the computations described above as tables have been computed which may be entered with the middle latitude and difference of longitude as arguments for the selection of the corrections. This table is printed in Radio Aids to Navigation (H. O. 205) and is available to the navigator. Excerpts from this table appear as figure 65.

Difference of Longitude

Mid-latitude	1°	1.5°	2°	2.5°	3°	3.5°	4°	4.5°	5°	5.5°
30°	0.2	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.2	1.4
31°	0.2	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.4
32°	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.3	1.4
33°	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5
34°	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5
35°	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.4	1.6

FIGURE 65.—Correction to be applied to radio bearing to convert to mercator bearing.

The correction is determined in the following manner. Suppose the dead reckoning position of the aircraft at the time the bearing was taken was latitude 30°56′00″ north, longitude 120°09′00″ west, and that a bearing of 239° (true) was taken by the radio direction finder station at Imperial Beach, Calif. From Radio Aids to Navigation (H. O. 205) the location of the station at Imperial Beach may be obtained and plotted as latitude 32°35′14″ north, longitude 117°07′54″ west. Then, from an inspection of the chart, the mid-latitude, to the nearest whole degree, would be 32°. This then is one argument.

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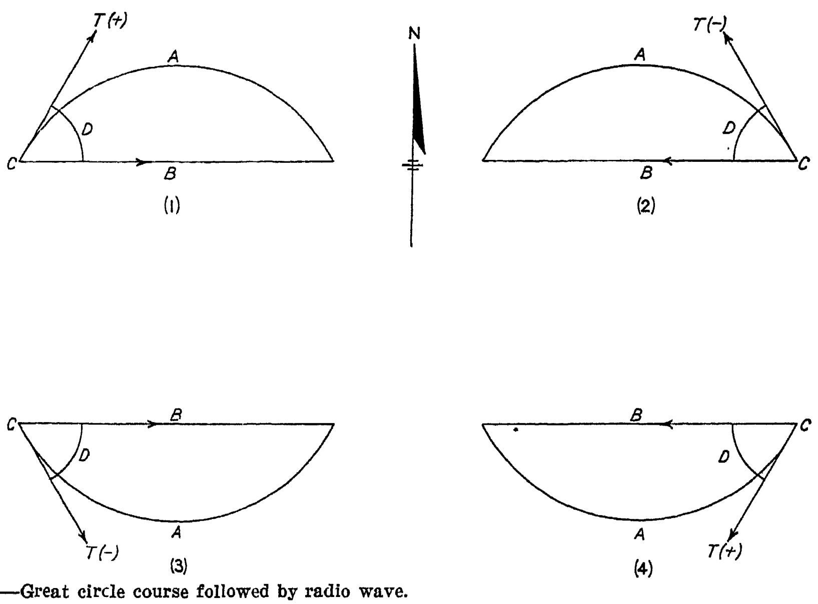
The other argument is the difference in longitude which is 120°09′00″ minus 117°07′54″ west, or 3°01′06″, or to the closest half degree, 3°.

Entering the table at the top with 3° difference in longitude and the side with 32° mid-latitude the value 0.8° is picked out. Note this is eight-tenths of 1 degree. This is the value of the correction, but it is necessary to determine whether it must be added to or subtracted from the bearing.

In the Northern Hemisphere, radio waves, or great circles, always convex toward the North Pole. The reverse is true in the Southern Hemisphere, where they convex toward the South Pole. Referring to figure 66, a rough sketch may be made to determine the sign to be applied to the correction. In case (1) in the Northern Hemisphere and radio direction finder to westward of transmitter, CT is the direction from which the bearing is coming.



A—Great circle course followed by radio wave.
B—Desired rhumb line for plotting.
C—Location of R. D. F.
D—Angle picked from table, i. e., difference between great circle and mercator courses connecting the two points.

FIGURE 66.

As measured by the radio direction finder, CB is the desired rhumb line. In this case, considering C as the center of a compass rose, it is seen that the direction CB is greater than CT. Therefore, the angle D is added to CT to obtain the desired bearing CB. The correction is marked (+) plus. In case (2), in Northern Hemisphere, it is seen that D is minus.

In case (3), in Southern Hemisphere, the correction is also minus.

In case (4), in Southern Hemisphere the correction is plus. These thumb rules are abbreviated for ready reference in volume 1 of Radio Aids to Navigation.

Referring again to the bearing received from Imperial Beach, 239° T., the correction of 0.8° is minus because it falls under the conditions of case (2). The radio direction finder at Imperial Beach is to the eastward of the transmitter in the aircraft, and it is in the Northern Hemisphere. The bearing to plot, therefore, is 239° T. minus 0.8° or 238.2° mercator.

Let us actually determine the position of an aircraft by the use of radio bearings taken by shore stations on the aircraft. At 1630 the navigator dropped a smoke bomb and circled around it, at the same time requesting that Point Hueneme, Calif. (NCA), Point Fermin, Calif. (NPX), and Point Arguello, Calif. (NPK), take bearings on the aircraft.

These stations report the true bearing of the aircraft from the stations as follows: NCA 233.4° T., NPX 257.2° T., and NPK 180° T. The mercator correction must be made to these bearings before they can be plotted on a mercator projection. The 1630 dead reckoning position is found to be latitude 33°30′ north, longitude 120°38′ west.

True bearing from station	Difference in longitude	Mid-latitude	Correction	Mercator bearing
	°	°	°	
NCA, 233.4° T.	1.5	34	−0.4	233° mer.
NPX, 257.2° T.	2.5	34	−.7	256.5° mer.
NPK, 180° T.	0	34	0	180° mer.

The mercator correction for NCA and NPX is minus because it falls under case 2, figure 66. No correction is necessary for NPK because there is less than 50 miles difference in longitude. By plotting these bearings the 1630 fix of the aircraft may be determined.

So far the case of the bearings being taken by shore stations has been covered. All patrol airplanes, as well as quite a large number of the smaller airplanes in the Navy, are supplied with radio direction finder equipment. It is possible to take a bearing on a shore station using the aircraft's radio direction finder. These bearings may be taken on the parent vessel, radio beacons, and commercial broadcasting stations. The problem here is a little different in that the azimuth indicator of the radio direction finder is mounted in the aircraft such that the zero reference is directly through the nose of the aircraft. The bearings taken are then relative to the aircraft's head. To obtain the true bearing of the station from the aircraft it is necessary to add the true heading of the aircraft at the instant the bearing is taken to the relative bearing; if the sum is greater than 360° it is necessary

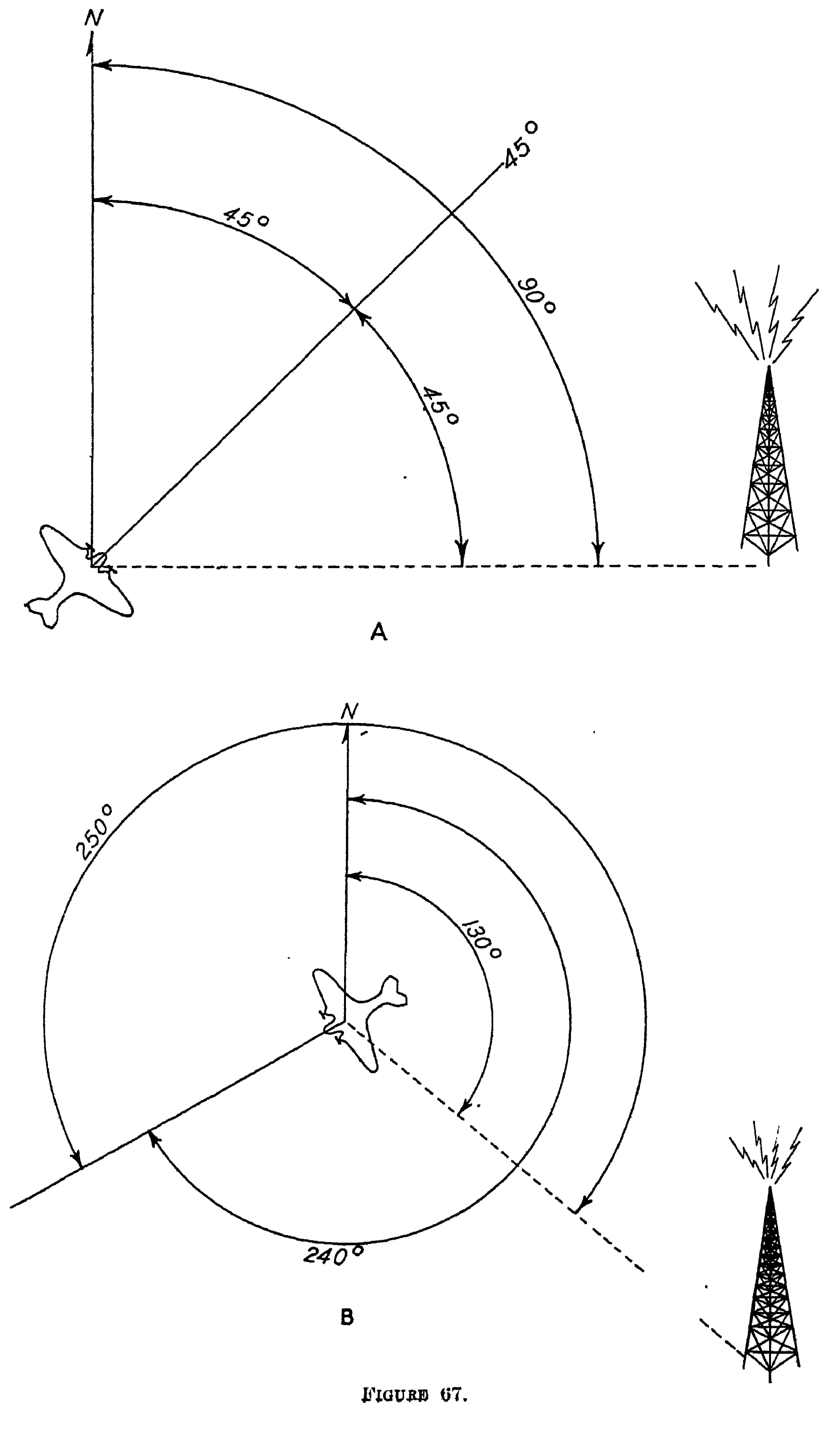


FIGURE 67.

to subtract 360° from the total to obtain the true bearing. Referring to figure 67–A, it is seen that the aircraft's true heading is 45° T. and the bearing relative to the aircraft's head is 45°. Thus, the true bearing is 45 plus 45 or 90° T., as shown. In figure 67–B the aircraft's heading is 240° T. and the bearing is 250° relative. The sum of these is 240° plus 250° or 490°. Subtracting 360°, the true bearing is found to be 130°. A study of the figure will reveal that the only arc doubled or duplicated is that one from true north to the station. Subtracting 360° then leaves this arc, which is the true bearing of the station from the aircraft.

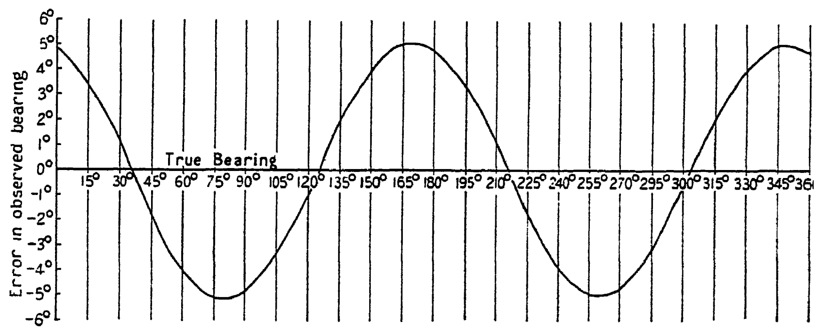


FIGURE 68.—Deviation curve of a radio direction finder.

The heading of the aircraft is determined by observing the magnetic compass at the instant the bearing is taken, then correcting this for deviation and variation to obtain the true heading. Since an automatic pilot steers a closer heading than the human pilot its use is preferred, if available, while bearings are being taken.

To obtain a relative bearing the radio direction finder operator has a correction to make to the bearing obtained by the R. D. F. This correction is known as the calibration error and is caused as follows: Generally speaking, radio waves follow the path of least resistance, and as a rule it may be assumed that for the band of frequencies covered by the average radio compass, this path of least resistance is a straight line from the transmitter to the radio compass. The higher conductivity of the metal, etc., around the vicinity of the radio compass tends to distort the wave front. The wave would be bent and strike the loop antenna in a different direction than normal. For this reason the bearing is in error. Fortunately it is possible to make a calibration chart for such errors and a typical chart is shown in figure 68.

It is not deemed necessary to go into the method of preparation of such a chart, but it suffices to say it is prepared by swinging the radio compass in much the same manner as the magnetic compass is swung.

The radioman usually corrects for this error before the bearing is given to the navigator; however, it is best that the navigator know of this and how it is made. Referring again to figure 68, suppose a bearing of 45° is obtained using the radio compass. It is seen that a correction of minus 2° is necessary so that the relative bearing is 45° minus 2° or 43° relative.

It is necessary, also, to make the mercator correction to these bearings before they may be plotted on a mercator projection.

To summarize the corrections that must be made to a bearing obtained by the plane's R. D. F., the following example is given: At "mark" bearing by radio compass is 87°, calibration correction for this bearing is 5° minus. Aircraft's heading by compass, 130°, deviation 2° west, variation 3° east.

Radio compass	87°	
Calibration correction	5°	(minus)
Relative bearing	82°	
Compass heading	130°	
Compass deviation	2°	W. (minus)
Magnetic heading	128°	
Variation	3°	E. (plus)
True heading	131°	T.
Relative bearing	82°	
True bearing	213°	T.
Mercator correction	1°	(minus)[1]
Bearing to plot	212°	Mer.

[1] Dependent on mid-latitude and difference in longitude.

When the method of correcting and plotting bearings is understood the inherent errors peculiar to radio bearings should be studied. This information is fully covered in H. O. 205.

Homing.—For homing a loop antenna located perpendicular to the center line of the aircraft is used. The pilot tunes in the desired station and heads the aircraft in various directions until the minimum signal is obtained. At this time the aircraft is either headed directly toward or away from the station. This direction is noted, then a course perpendicular to it is flown for 10 minutes and another minimum obtained. The station then lies in the direction toward which the two bearings are converging. The pilot flies in this direction, keeping the aircraft

headed so as to continuously receive a minimum signal. By doing this the aircraft is headed at all times toward the station and must therefore pass over it. If a strong cross wind is encountered it must be remembered that the shortest distance to the station will not be flown. Instead, the aircraft will be drifted in such a manner as to fly a curve and finally pass over the station headed directly into the wind. To offset this, a wind correction angle may be applied and the direction or bearing of the station checked occasionally. Figure 69 illustrates the effect of the cross wind.

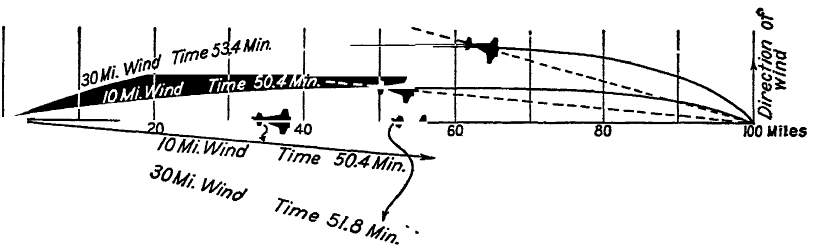


FIGURE 69.—Comparison of time required to "home" on the minimum and on a heading corrected for drift.

Homing is mentioned here as a method of navigation which may be used provided the transmitting station lies along the desired track, or at the ultimate destination. It should be borne in mind that although the aircraft flies along the "paths of silence" in approaching the station, no minimum can be obtained when over the station. This fact assumes tremendous importance if the aircraft is coming into the station above the clouds, and thus out of sight contact. Homing may be done by using the homing loop built into the wings of the aircraft or the R. D. F.

RADIO-RANGE STATIONS

The purpose of a radio range is to serve as a directional aid to the pilot when flying along an airway.

A radio range station operates on the frequency band of 200 to 400 kilocycles. It broadcasts the Morse equivalent of the letter "A" which is a dot followed by a dash, and the Morse equivalent of the letter "N" which is a dash followed by a dot. This is accomplished by four radio-transmitting towers located at four corners of a rectangle. Two diagonal towers broadcast the letter "A" and the other two broadcast the letter "N" as shown in figure 70.

Where an "A" circle overlaps the "N" circle, both the "A" tone and the "N" tone will be sent simultaneously. Since the two tones are timed so as to interlock, the resulting signal will be a long monotone dash. This is the "on course" signal or the "beam." Now, refer to figure 71.

It is shown that the beam is 3° wide. Beam widths will vary somewhat according to the radio range station. There is also indi-

cated a bisignal zone in which not only an undertone of the beam can be heard but also the "A" or the "N" tone will predominate. When passing out of the bisignal zone, the "hum" or beam tone is very loud near the beam with the "A" or "N" tone much weaker. Going away from the beam, the "hum" becomes weaker until the "A" or the "N" off course sectors are reached.

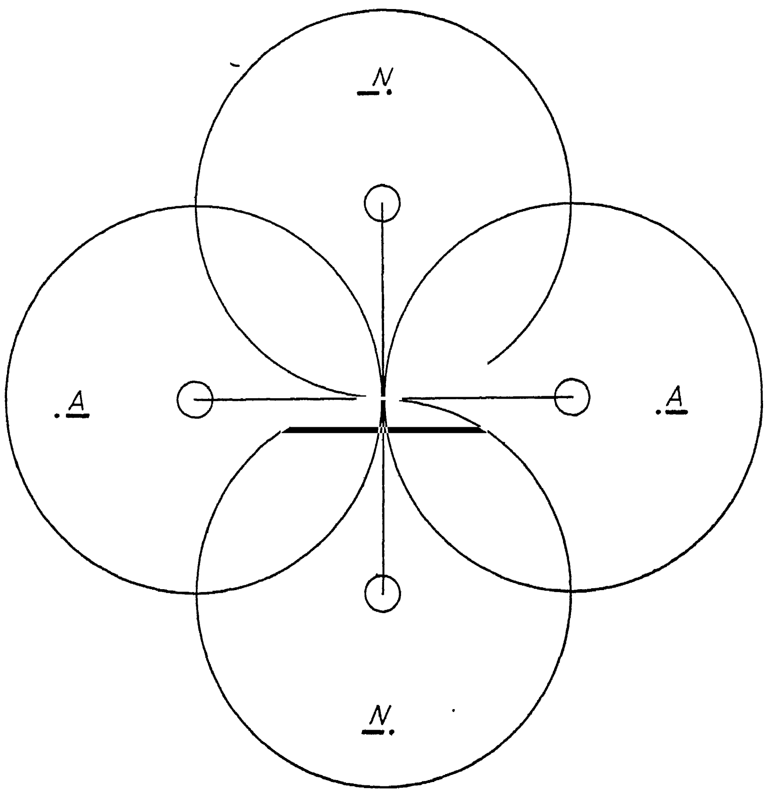


FIGURE 70.—The four transmitting towers of a radio range station.

Not only do these radio-transmitting towers transmit an "A" tone or an "N" tone but at frequent intervals (every 28 seconds), the call letter will be transmitted for a duration of 2 seconds, first on the "N" towers and then on the "A" towers. The strength of the call letters varies exactly with the strength of the "A's" or the "N's" which are being received. The strength at which these identification letters are received identifies another point on the sketch which is called the twilight band. This is the border between the bisignal and the beam. In the "N" bisignal zone, the first station identification signal heard would be the one broadcasted by the "N" towers. The second station identification signal transmitted by the "A" towers

would be much weaker. Theoretically, when approaching the beam, the identification signals become more and more of the same strength. Just before the "A" and the "N" identification signals become the same strength, the twilight band is reached. The ear is not accoustically sensitive enough to detect this change at exactly the right instant, so the extent of the twilight band depends mostly on the sharpness of the ear.

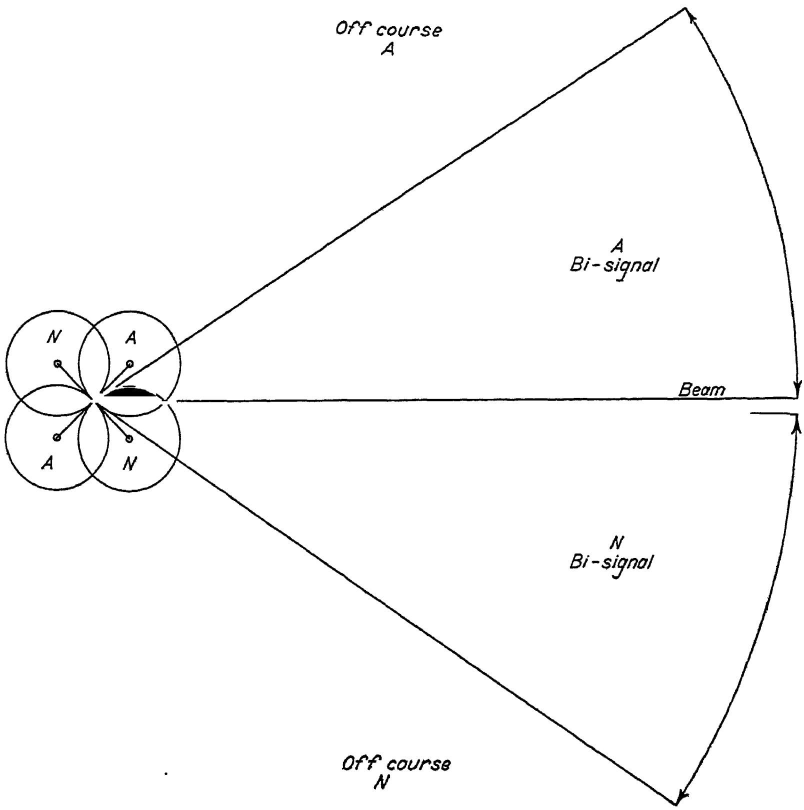


FIGURE 71.—The pattern of signals from a radio range station.

(*d*) The "N" sector of all radio range stations is the sector in which lies the true north bearing from the range station. If the course of a signal is true north, the sector to the *LEFT* or *WEST* is the "N" sector.

The cone of silence.—This is a space in which no signals are heard. As the name implies, it is an inverted cone with the apex at the beam station. If the aircraft antenna has a vertical component, and the aircraft is on the beam approaching the transmitting station, the beam signal increases in volume as the distance to the station decreases. This increase will continue at a constant rate until just

before the cone of silence is reached, at which time there will be noticed a rapid build-up of signal strength and then silence. After passing through the cone of silence, the very loud signal is again heard, rapidly diminishing to a constant rate of decrease in volume as the distance is increased away from the station.

In flying the beam, the beam signals may possibly fade, and when this occurs, the pilot may believe that he has passed the cone of silence. There is no need for this belief because in order to pass through the cone of silence, there must occur the rapid build-up, the silence, the build-up and then the diminishing of the beam signal. If the pilot observes closely for these characteristics, he will have no difficulty in locating the true cone of silence.

The range station which gives the true cone of silence, that is, vertically above the beam station, is one in which the "A" and the "N" quadrants are 90°. Where the "A" or the "N" sectors are unequal, the cone of silence will be canted from the vertical. Peculiarities exist at some stations where no true cone of silence will obtain.

Marker beacons.—It has been described how the pilot may establish himself directly over a station which has a vertical cone of silence. Additional markers are established along the airways to aid in obtaining "fixes" at other points. At the time of this writing (1939) the following type markers have been established:

A class "M" marker beacon is a low-powered, nondirective radio station which transmits a characteristic signal, such as "H" (. . . .) once every 10 or 12 seconds. Class "M" marker beacons are normally equipped for voice communication with aircraft. These marker beacons have a range of from 3 to 10 miles depending on the weather conditions and the type and condition of receiving equipment being used. Marker beacons are normally placed at the intersection of two range courses indicating when to tune to the next station. In such a case the characteristic signals are transmitted on the same frequencies as the adjacent radio ranges so that they can be heard if the receiver is tuned to either range. Marker beacons may also be placed on or near some obstruction, such as a radio tower, or at some particular point along the airway. A marker beacon does not operate continuously, but is turned on when the local ceiling is more than one-tenth overcast or the visibility is less than 5 miles, or at any time on request. This is because a marker beacon is used by the pilot to check his position when flying "over the top" when the ground cannot be seen.

Class "Z" markers are located at range stations and give a positive indication at the time a cone of silence should be received. The "Z" type marker has an antenna which produces a high intensity signal in a space immediately above the station, roughly corresponding to a cylinder. "FM" markers are located so as to give a positive indica-

tion of the user's position along the airway. The "FM" marker has a type of antenna which produces a high intensity signal in a space immediately above the station, roughly corresponding to a thick fan. This fan is placed so that its plane is at right angles to the airway.

The signals from both the "Z" and "FM" type markers are modulated with audio tone of 3000 cycles. This tone may be heard in the headphones when a signal is being received. The tone is not keyed at the "Z" marker stations. The tone *is* keyed at the "FM" type stations with a number of dashes, depending upon which leg of the range the marker is located. If the marker is on the north leg or the first leg clockwise from north, the tone is keyed with one dash. If the marker is on the second, third, or fourth leg clockwise from north, it is keyed with two, three, or four dashes, respectively.

Operation of the marker receiver will not affect either loop or beam reception. An indicating light located on the instrument panel should light to full brilliancy when a strong signal is received from either the "Z" or "FM" marker stations. The time duration of the light indication will vary for given stations due to differences in installation practices aboard different airplanes. Eventually it is hoped that all marker receivers will be adjusted to give the same indication under given conditions. No volume control is used on this receiver as it is fixed in sensitivity.

Automatic direction finders.—Recently, experimental automatic direction finders of several types have been developed. These indicate:

1. In full automatic position, a continuous bearing toward the station.

2. Freedom from 180° ambiguity.

These compasses, however, cannot operate as a fully automatic direction finding device during conditions of heavy precipitation and static, but may be altered by means of throwing a switch to provide operation with a second shielded loop, in place of the regular sense antenna, but *with* 180° ambiguity. As a result of this arrangement, continuous headphone signal is provided by this second loop, which is maintained at the position of maximum pick-up relative to the reference station.

Its greatest advantage lies, of course, in the fact that once tuned to a station it continues to indicate the direction of that station, irrespective of the heading of the airplane, whereas the loop of the ordinary radio compass must be manually adjusted to the null position whenever it is desired to take a bearing. The continuous, automatic, nonambiguous bearing is a tremendous aid in solving orientation problems. The relative and magnetic bearings of the range station are given at all times. It checks the cone of silence unmistakably, the pointer swinging around 180° and pointing in the opposite direction in the time it takes an airplane to cross the cone of silence. This

device provides continuous manually controlled aural signals while functioning as an automatic direction finder.

Range stations are not placed at the landing field, but whenever possible are so situated that there will be one beam which comes in directly over the landing area and over the best approach area. Usually they are placed down wind from the prevailing bad weather winds of the locality.

Airport localizer stations are located immediately adjacent to the landing area, and one of the bearings falls directly over the field, or along the runway, as the case may be.

Weather broadcasts.—Voice broadcasts which include weather information are with a few exceptions transmitted on the range frequency without any interruption of the beam signals. It would seem that this would create a great deal of interference but this is eliminated by the use of the five tower system of beam and voice broadcasting. By modulating the range signals from 830 to 1252 cycles and by blanking out the voice transmissions at these modulated frequencies, it is found possible to tune out either one or the other broadcast by means of filters located within the receiver. Since a large number of aircraft are not equipped with these filters, it is found that by tuning the receiver 1 kilocycle higher, the range signals will predominate. In this manner the pilot should experience no difficulty in listening to either the range or the voice broadcasts.

This five tower system of broadcasting is called the Adcock vertical radiator type of range stations. The four towers which transmit the range signals are the same as described above. In the center of the four towers is one antenna which is used for voice signals. The carrier wave of the center antenna is on at all times at the same frequency as the beam. In using this type of beam station, the "A" and the "N" signals are modulated to 1020 cycles (audible tone). The filter, as mentioned above, cuts out everything but audio frequencies in the vicinity of the 1020 band. The other band of the filter cuts out everything in the vicinity of the 1020 band. In other words, the filter cuts out the range signals on the one switch, permitting the voice signals, and on the other it permits the beam signals, to come through without interference from the voice broadcasts.

Certain peculiarities must be guarded against when flying the radio beam. It is known that the on course signal is heard when the "A" tone and the "N" tone overlap and both are heard with equal intensity. Due to the absorption of radio waves by mountains, tall buildings, ore deposits, etc., there may be other instances in which both tones, the "A" and the "N" will be of equal intensities. Naturally, there will be another beam which is not the true beam formed

which is called a multiple beam. They are usually found in either the "A" or the "N" bisignal zones near the beam. They take the form of a long ellipse with the longer axis parallel to the beam. There should be no difficulty encountered whenever the pilot finds himself in a multiple beam. If he continues his course he will eventually run out of the multiple beam into either bisignal tone. If he believes that he is in a multiple beam, by changing course in either direction he will find that the same bisignal note is heard. The bisignal tone heard will establish the sector he is actually in with reference to the true beam.

Besides being subject to the phenomena of forming multiple beams, the true beam may bend or change direction due to any of the effects which caused multiple beams. There are two waves to a radio signal, the ground wave and the sky wave. The sky wave is reflected by an electrically ionized region in the stratosphere known as the Kennaly Heaviside Layer. At the point where this reflected wave again strikes the earth the signal is again picked up by the receiver. During evening and morning twilight, the Heaviside layer shifts vertically, which causes the radio beams to change their direction more during these periods. Care must be taken when following the beams during these times. The new Adcock vertical radiator type of range stations eliminate this night effect to a great extent.

If, when flying the beam, there is a shift in its direction, the pilot should continue on the beam because eventually it will arrive at the beam station. A let-down through the overcast should never be attempted if there is any doubt in mind that a multiple or bent beam is being followed. The terrain under the beam may be altogether different from that shown on the chart or over which the pilot knows that he is flying when on the true beam.

Before leaving the discussion of establishing the position of the aircraft when it is on the beam, there is one more method of establishing the position of the aircraft by use of the beam receiver. When not on an established airway, but the aircraft is following a radio beam and arrives at the intersection of another beam he may plot his position on the chart. This discussion, however, must not be misconstrued with the "M" type markers which are found at most beam intersections which occur on airways.

The pilot when approaching a crossing beam may maintain his heading by the directional gyro and tune his receiver to pick up the crossing beam. He may possibly at first start receiving an "N" bisignal tone and then he will reach the twilight band and then the beam of the other station. Where the two beams cross on the chart will definitely establish the position of the aircraft. The pilot may then tune his receiver to pick up the original beam.

Beam identification.—Each experienced pilot has his favorite method of beam identification. Some methods of identification work better than others under certain circumstances, such as the location of the beams, whether the beams are 90° apart, and the location of the aircraft with relation to the beams. This discussion will merely name some of the methods which are now in use and describe two of them.

1. *The outbound course method.*—Used when the airplane is close to the range station and when coming in on the beam for a let-down on instruments.

2. *The 90° method.*—Works extremely well in small quadrants, but not suitable in quadrants greater than 90°. The sector in which the aircraft is located must be known to use this method.

3. *Identification by sound and bearing.*—This method works very well in large quadrants, but requires a comparatively long time to execute.

4. *The 90° turn system.*—This system is a purely mechanical one and the beginner cannot go wrong if he uses this method. However, it can be used successfully only with 90° quadrants, with little or no cross wind, and when fairly close to the range station.

5. *The true fade-out method.*—This method establishes the beam in a comparatively short time and is simple in its execution. If the beam is reached near the station, the pilot would probably miss the cone of silence or the "Z" marker and also he would be confused by the various beam signals heard in this locality, however, the possibility of the pilot coming right out on the station, or very close to it, is very remote.

The pilot of an aircraft hears an "N" signal which places him either at *X* or *W*. He then assumes a heading which is the bisector of the quadrant in which he finds himself. He then tunes the volume control down and if, as he continues on the bisector course, the signals fade he knows that he must have been at *W*. He therefore makes a 180° turn. He continues on this new heading until he comes to an on-course signal. He crosses the beam and turns away from the station, picking up the beam again during his turn and following it to the range station. As is shown in figure 72, it will be noted that the course of the aircraft is zig-zag on the beam when the pilot first picks it up. By doing this, he is able to determine the magnetic course of the signal and the compass heading of the aircraft which will keep it on the beam. The difference between the magnetic heading of the aircraft and the magnetic course of the signal will be the wind-correction angle. The one bad feature of this method is that which arises when the position of the aircraft is close to the actual bisector of the sector. It can readily be seen that if this condition arises, it

would take considerable time for the aircraft to intercept the station without ever coming into a beam. In order to speed up this method, after the quadrant is identified by the fading of the signal tone, the pilot may change his course either to the right or the left about 40° and maintain this new heading until a bisignal tone is heard. If the course was changed to the right and the aircraft went from an "N" zone into an "N" bisignal zone, the pilot knows that he is approach-

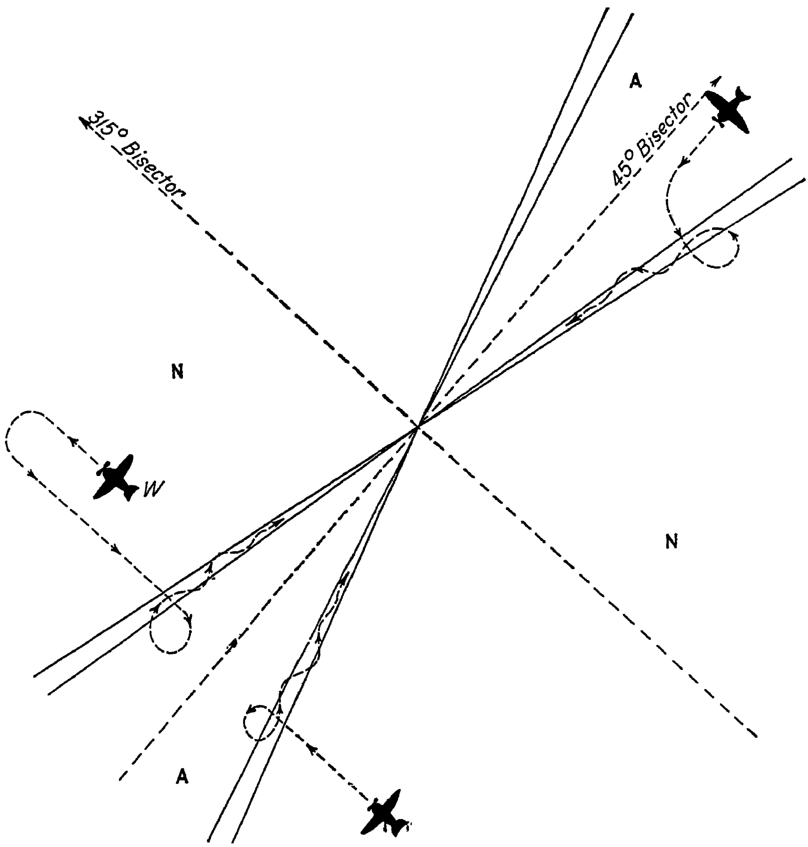


FIGURE 72.—The true fade-out method.

ing the right-hand beam of the quadrant in which the aircraft is flying. By then changing the heading of the aircraft so that the beam will be crossed at 90°, the pilot will soon cross the beam and make the usual turn away from the station and continue as before.

6. *The parallel course method.*—This method is simple and easy to fly. It locates a beam rapidly and requires few turns. It should not be attempted in quadrants greater than 90° when there is a cross wind.

Figure 73 represents a range station with an aircraft receiving an "N" note signifying to the pilot that he is either at *X* or *Y*. If the pilot wishes to approach the station on either the north or the south leg, he will assume a heading parallel to the east-west legs. The pilot supposes that he is at *Y*. He then heads 090° and if the signal becomes louder he knows that his assumption was correct. He then continues this heading until the aircraft comes into the on-course signal of the north leg. The pilot continues his heading, passing through the beam, and then makes a 270° turn away from the station

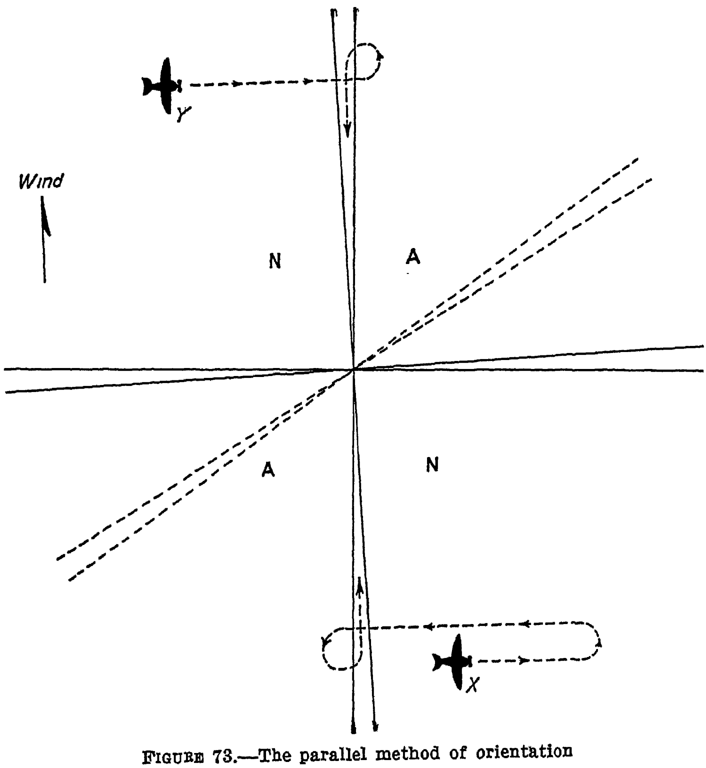


FIGURE 73.—The parallel method of orientation

and follows the beam to the station. If his original assumption was incorrect, when he assumed his heading of 090° the signals would have become weaker. This would have indicated to the pilot that he was at *X*, and by making a 180° turn and continuing this heading he would intercept the south leg, and by again turning away from the station and coming around onto the beam he could follow this leg into the beam station. It can readily be seen that if the north-south leg was canted, as shown by the dotted lines, and a strong wind was blowing from the south, the pilot at *Y*, using this method, would never reach the north leg. But due to its simplicity this method is

excellent for the beginner when using a beam station as shown in the sketch.

When flying on a radio range the following instructions should in general be adhered to:

(*a*) *Keep to the right of the beam.*—Pilots approaching the radio range station, and close to it, may fly along the on-course signal. Aircraft which are departing from a station along a civil airway shall keep to the right of the radio range course as projected along the airway.

(*b*) During orientation, if the beam is reached near the range station, the turn should be made *AWAY* from the station. If doubt exists as to the proximity of the station, the turn should be made to the *LEFT*.

(*c*) After picking up a beam the aircraft should zigzag or "bracket" the beam to definitely establish the bisignal tones and check the magnetic course of the beam as well as solving the wind correction angle.

(*d*) During orientation the volume control should be kept as *LOW* as possible, especially when using the fade-out method. This procedure will also enable the pilot to establish more clearly the cone of silence.

(*e*) In case the aircraft drifts off the beam, a definite change of course should be made in order to return in the shortest possible time.

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CHAPTER V

CELESTIAL NAVIGATION

Celestial navigation is the science of determining position on the earth's surface by means of observations of celestial bodies—the sun, moon, planets, or stars.

Because of the many unknown conditions entering into dead reckoning navigation and the possibilities of large resultant errors, it is desirable to check the accuracy of the estimated track and ground speed. Celestial navigation and radio bearings offer the best practical means for this check when the aircraft is out of sight of known landmarks. Celestial navigation must be relied upon as the primary means of checking the dead reckoning as radio signals are not always available.

Modern celestial navigation started about two centuries ago with the invention of the sextant, the marine chronometer, and the printing of the first Nautical Almanac, but because it involved unfamiliar processes of solution it appeared complicated and mysterious to the average person. The rapid strides and importance of aviation have created new and intense interest in this subject. The necessity for speed and simplicity in solving the astronomical triangle has encouraged the development of short methods or the simplification of the older ones, so that now practically anyone can apply these newer methods with but little basic knowledge of the subject of either astronomy or navigation.

Three things determine the accuracy with which a position can be determined by celestial observations—the instrumental equipment, the skill of the observer, and the conditions under which the observations are made. The pilot always keeps a record of course and distance, and at any time can determine his approximate position. This approximate or dead reckoning position is used as a base or starting point from which observations are worked and plotted on a chart.

A celestial observation consists of measuring the angular distance of a celestial body above the horizontal with an instrument known as a sextant or octant and noting with a good watch the exact time of the observation. As these observations are the most difficult part of the work in celestial navigation, good results obviously require continued practice.

After the sight is taken, a line of position is then computed, using for data, the dead reckoning position, the exact Greenwich civil time

of the observation, the true measured altitude, and the celestial coordinates of the observed body taken from the Nautical Almanac. By means of specially designed tables, the computations for the line of position have been reduced to simple arithmetic. Plotting the position line on the chart is then just as simple as measuring a course.

The following equipment is required for celestial navigation—sextant, or octant; chronometer (accurate watch); current Nautical Almanac; altitude and azimuth tables for computations; proper navigation charts, and other instruments such as dividers and parallel rulers.

THE CELESTIAL SPHERE

Before the astronomical triangle used in all examples of celestial navigation can be solved, it is necessary to have some system of celestial coordinates similar to latitude and longitude on the earth, so that positions of places on the earth can be compared with the positions of all celestial bodies. For this purpose the heavens are considered to form a large dome or sphere of infinite radius, called the celestial sphere as shown in figure 74. This sphere has the same center as the earth. The system of its coordinates corresponds very closely with those of the earth, although the names are somewhat different.

The celestial bodies, with the exception of the planets and the moon, are more or less fixed in space. The rotation of the earth on its own axis, from west to east, results in an apparent daily rotation of the celestial sphere in an opposite direction, thus the earth is generally considered as being stationary while the celestial bodies appear to rise in the eastern and set in the western parts of the earth's horizon.

The earth's axis extended cuts the celestial sphere in two points called the north and south celestial poles. It is about this axis that the celestial sphere apparently rotates.

The plane of the earth's equator extended intersects the celestial sphere in the celestial equator, or equinoctial. The equinoctial is everywhere 90° from the celestial poles, just as the equator is 90° from the earth's poles.

Distance measured north or south from the equinoctial is known as declination. Declination on the celestial sphere corresponds to latitude on the earth and is measured in degrees of arc to the north or south of the equinoctial. Declination is abbreviated in the Nautical Almanac with a plus (+) sign for north or a minus (−) sign for south declination.

The plane of the Greenwich meridian extended cuts the celestial sphere in the Greenwich celestial meridian, and, as on the earth, is the meridian from which east and west distances are measured along the equinoctial in terms of arc of hour angle. The distance from the Greenwich celestial meridian is known as *Greenwich hour angle*, but

unlike longitude which is measured either east or west from Greenwich to 180°, it is always measured to the westward from 0° through 360°.

Local hour angle is the difference in longitude between the meridian of a celestial body and the meridian of the observer. Local hour angle corresponds to the measure of a certain difference of longitude on the earth. It may be measured either east or west of the observer's meridian

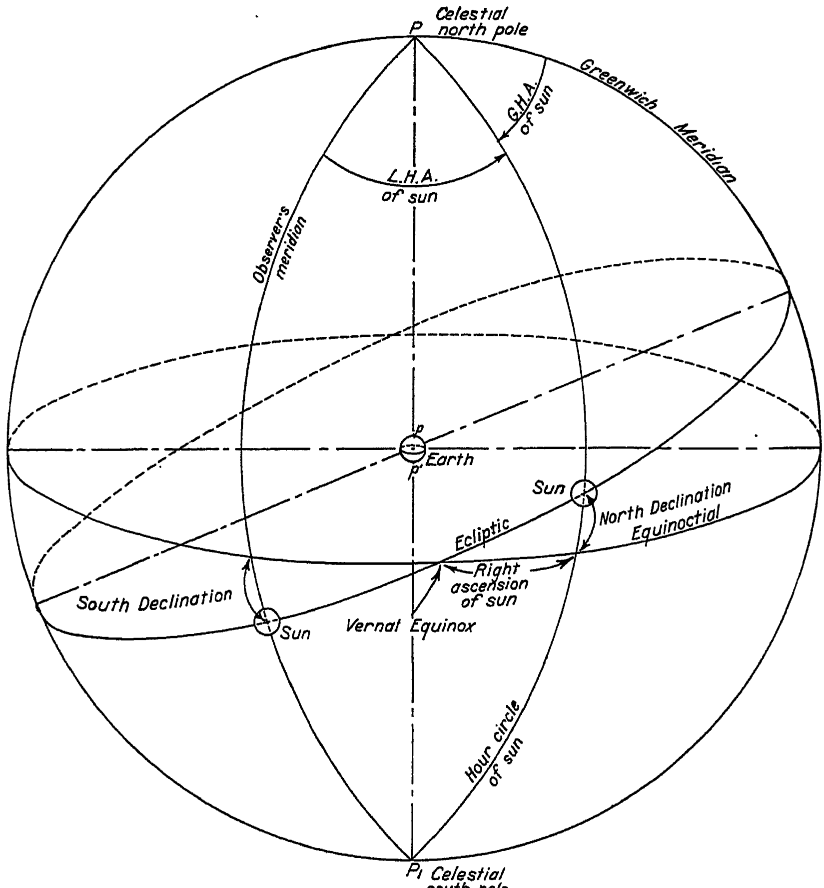

FIGURE 74.—The celestial sphere.

so that the hour-angle value will not exceed 180°. The direction of the local hour-angle measurement must be indicated as either east or west.

The point known as the *vernal equinox*, occupied by the center of the sun at the beginning of spring, may also be used as a zero point for measuring right ascension in the heavens or what corresponds closely to longitude on the earth. The vernal equinox is one of the two intersections of the equinoctial with the ecliptic (the apparent yearly path of the sun around the earth).

Right ascension is the arc measured along the equinoctial between an hour circle or meridian circle passing through the vernal equinox and an hour circle passing through any other celestial body. It is always measured to the eastward in time, or arc, from 0^h to 24^h, or 0° to 360°. The position of any celestial body may then be fixed in the heavens by knowing its right ascension and its declination. (See star chart in Nautical Almanac). Knowing the celestial body's right ascension, its Greenwich hour angle may be easily obtained, and it can then be readily plotted by the coordinates of Greenwich hour angle and that of declination. This celestial point may be also plotted on the earth by using the coordinates Greenwich hour angle as longitude and substituting latitude for the declination of the body.

The *zenith* of a place on the earth is the point in the celestial sphere directly overhead. The *nadir* is the point directly underneath.

The *celestial horizon* is a great circle of the celestial sphere whose plane is perpendicular to the zenith-nadir axis, 90° from the zenith.

The *altitude* of a celestial body is its angular distance above the celestial horizon, measured on a vertical circle passing through the zenith and the body.

The *azimuth* of a celestial body is its angle of bearing at the zenith of a place on the earth between the meridian and the vertical circle passing through the body, and is measured along the horizon.

A great circle that passes through a place on the earth and both its poles is a *meridian;* on the celestial sphere, the great circle that passes through a celestial body and the celestial poles in an *hour circle.*

Polar distance is the angular distance from a celestial pole measured on the hour circle passing through the celestial body. It is equal to 90° plus or minus the declination.

Zenith distance is the angular distance from the zenith measured on the vertical circle passing through the celestial body. It is equal to 90° minus the altitude.

The following are corresponding terms applying to the earth and the celestial sphere:

Earth:	*Celestial sphere:*
North Pole.	North Celestial Pole.
South Pole.	South Celestial Pole.
Equator.	Equinoctial.
Latitude.	Declination.
Longitude.	Greenwich hour angle and right ascension.
Difference of longitude.	Local hour angle, or the difference between any two right ascensions.
Bearing, or Azimuth.	Azimuth.

THE ASTRONOMICAL TRIANGLE

By connecting the celestial pole, zenith, and a celestial body with great circles, a spherical triangle known as the astronomical triangle is formed. The solution of this triangle gives the altitude and azimuth which is used to plot the line of position.

The astronomical triangle formed in north latitude, *PZM*, is illustrated in figure 75. *P* and *P'* are the celestial poles. *QQ'* the equi-

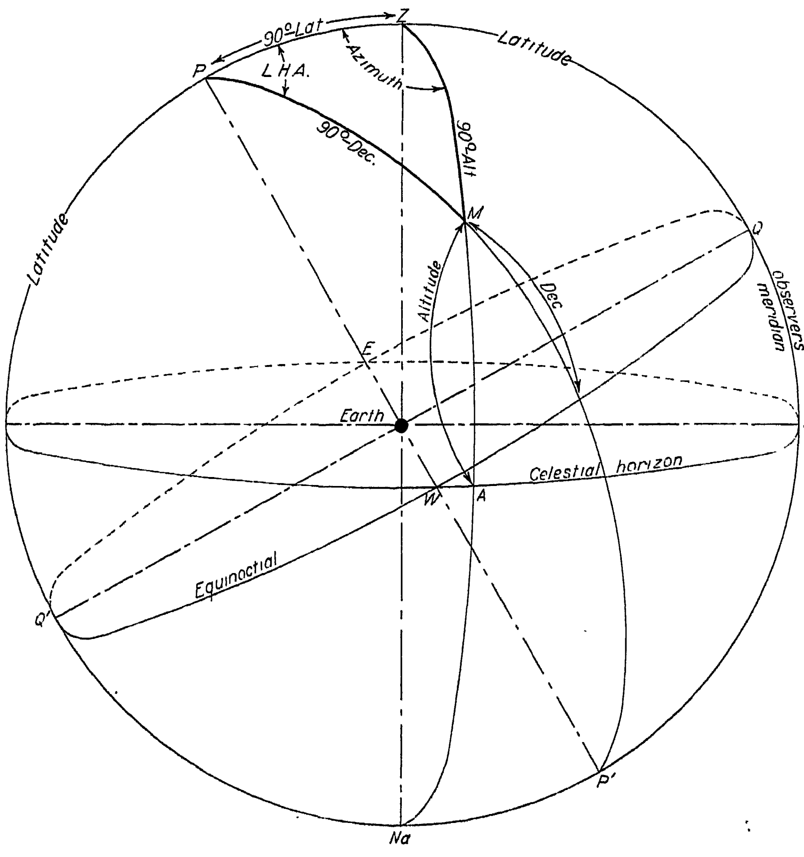

FIGURE 75.—The astronomical triangle.

noctial, *Z* the zenith of the assumed or dead reckoning position, and *M* a celestial body. The circumference *PQP'Q'* is the meridian of the assumed position. *PM* is part of the hour circle of the star *M*. The angle *ZPM* between the hour circle and the local meridian is the local hour angle. The angle at the zenith *PZM* is the azimuth or bearing of the star from *Z*. *ZM* is part of the vertical circle that passes through the zenith and the star. The distance from the equinoctial to the star in arc is its declination and is found in the Nautical Almanac. As the

distance from the pole to the equinoctial is 90° then $PM = 90° -$ declination.

From the horizon to P, or the equinoctial to Z, is the latitude of the assumed position so that $PZ = 90° -$ latitude.

The difference between the longitude of Z and the Greenwich hour angle of the star equals the local hour angle (angle ZPM). The Greenwich hour angle is found in the Nautical Almanac.

From the assumed position, with the latitude, hour angle, and declination, the angle PZM or azimuth and the altitude (AM) of the star are determined. The navigational tables used for solution are so arranged that it is not necessary to subtract the various values from 90°. Instead, entry is made directly with the three known arguments, and the values for the altitude and azimuth are obtained directly.

A comparison is then made between the computed altitude at the assumed position with the corrected sextant altitude as measured at the true position. The difference gives the altitude intercept. The azimuth is then plotted from the assumed position, the intercept laid down, and the line of position drawn through the latter point at right angles to the azimuth.

THEORY OF CELESTIAL NAVIGATION

An observer on the earth's surface sees the altitude of a celestial body rise or set with a change in watch time. The altitude also changes with a change in the observer's position. If an observer moves 1 mile directly toward or directly away from a celestial body its altitude will change 1 minute. Celestial navigation is based upon this fact.

It is important to remember that distance on the earth's surface is measured in degrees as well as in miles.

Any celestial body is directly over some point on the earth's surface. This point is called the subsolar or substellar point and is generally referred to as the geographic position of the body. It is fixed by the body's coordinates, Greenwich hour angle and declination, which are plotted on the earth as longitude and latitude.

To an observer at this geographic position, the body would be in the zenith and the altitude would be 90°. Suppose another observer to be 300 miles (5°) away from the geographic position in any direction; to this observer the body's altitude would be 85°. If a circle should be described on a chart with the geographic position as a center, and a radius equal to the zenith distance, in this case 5°, the altitude would be the same everywhere on the circle. Such a circle is known as a circle of position, or circle of equal altitude. Now, if a second star should be observed, its zenith distance would determine a second circle of equal altitude and the intersection of the two circles

would determine the observer's position. There would, of course, be two intersections, but one is disregarded because of a knowledge of the dead reckoning position or because of the observed azimuth of the stars, as shown in figure 76.

A circle of position, then, can be plotted on a chart by locating the geographic position of a celestial body, and with this point as a center draw a circle with a radius equal to the zenith distance. As stated before, the zenith distance is 90° minus the altitude, and may be plotted on the earth either as degrees or nautical miles, using the relation one degree equals sixty nautical miles.

If it were possible to determine the correct azimuth, an observer could easily determine his position from the bearing and distance

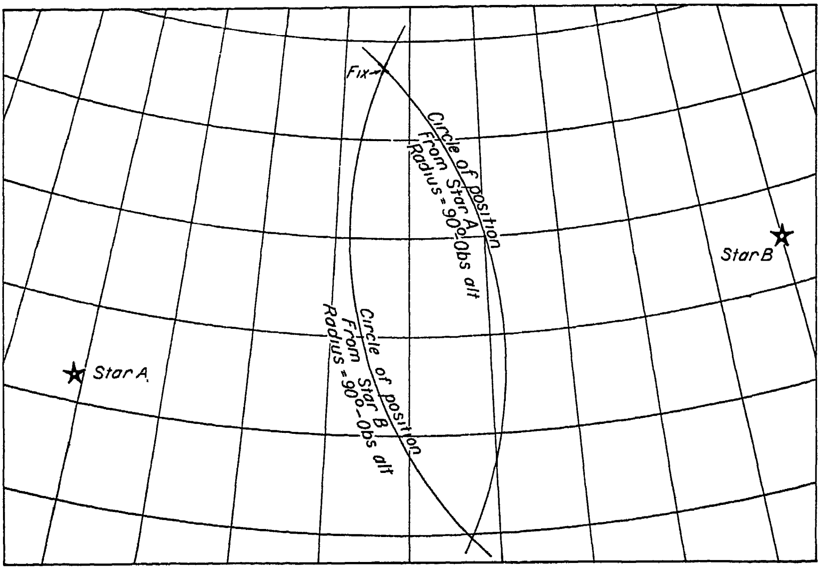

FIGURE 76.—Fix from two circles of position.

from the geographic position of the celestial body. There are two reasons why this cannot be done. With present instruments it is not possible to determine the exact azimuth, and the excessive length of the azimuth line results in a small error in bearing causing a large error at the circle of position.

Charts are not generally made to permit drawing the circle of position accurately. As the radius can be as much as 5,400 nautical miles, a chart to permit such a long distance to be drawn must either be too large for practical convenient work or the scale entirely too small for accurate work.

To plot a circle of position on the large-scale charts in common use, the navigator starts with an assumed position, usually the dead-reckoning position. For this position, by the use of nautical tables,

he computes the altitude and azimuth of the star for the instant of time of observation; 90° minus the computed altitude is the distance from the assumed position to the geographic position of the star and the azimuth is the bearing. If the observer were on the position circle of the assumed position, the measured altitude would be the same as the computed altitude. If, however, he were on some other circle the two altitudes would not be the same. The difference between the two altitudes in minutes of arc would be the distance in miles from the assumed position to the circle through the true

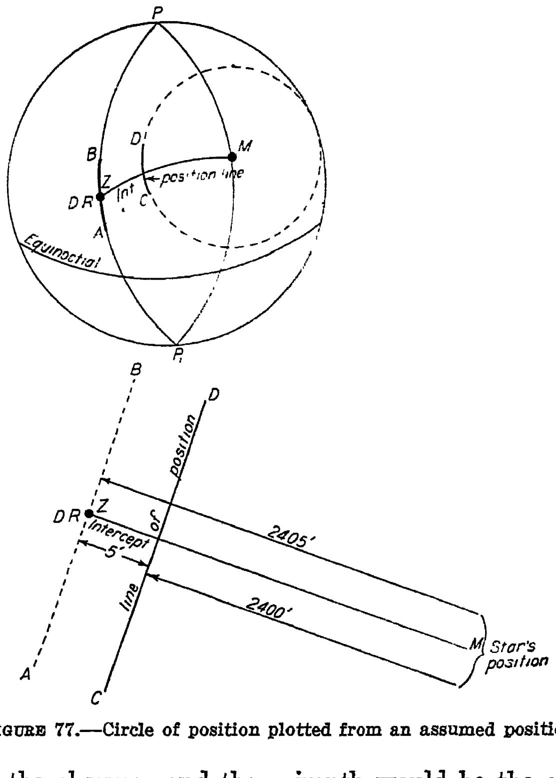

FIGURE 77.—Circle of position plotted from an assumed position.

position of the observer and the azimuth would be the approximate direction.

In figure 77, Z is the observer's assumed, or dead-reckoning position. M is the geographical position of the celestial body. AB is a small portion of the arc of the observer's circle of position. MZ is the zenith distance of the body, or the radius of the computed position circle which is equal to the complement of the computed altitude or $90°-Hc$. The observed altitude is Ho, then $90°-Ho$ is the length of the radius of the arc CD, or the true circle of position. The altitude intercept is the distance from Z to the arc CD. Suppose the computed altitude is 49°55′ (the radius is then 2,405 miles) and

that the observed altitude is 50°00′ (the radius 2,400 miles), then the distance is *Hc–Ho* or the arc of the true circle of position is located 5 miles in the direction of the observed body.

When the observed altitude is greater the true-position circle is nearer the star, and when the computed altitude is greater the true-position circle is farther from the star. Ordinarily only a small portion of the circle is used. As the radius is of such a length a small arc of the circle may be represented by a straight line without material error. Such a line is called a *line of position* to distinguish it from the entire circle. One line of position will not definitely locate the observer. Much information may, however, be gained from one line. By observing a body bearing at right angles to the

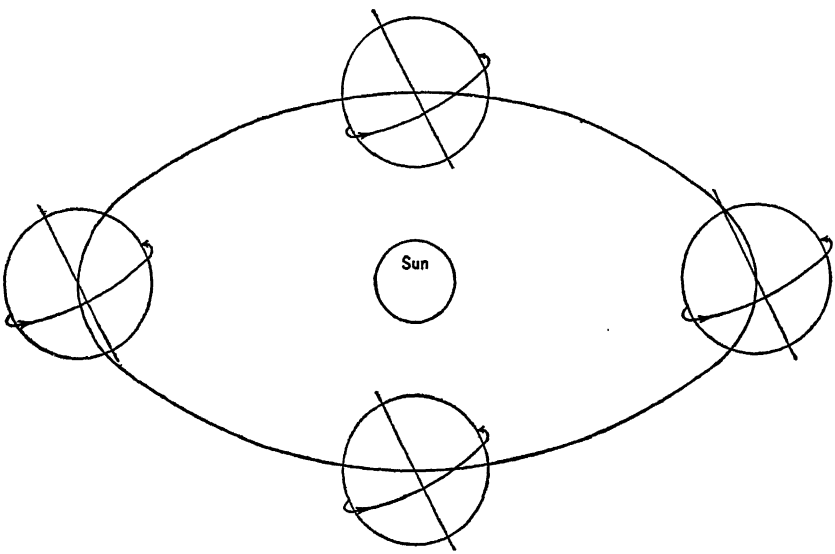

FIGURE 78.—The solar system.

course, the line of position will indicate whether or not the aircraft is following the course line. An observation on a body bearing dead ahead or astern will indicate the speed being made over the ground.

TIME

The Nautical Almanac contains all data from which hour angles and declinations of celestial bodies may be determined. All values tabulated in the almanac are based on Greenwich civil time. In order to use the almanac correctly the navigator must have a thorough knowledge of time.

The solar system, as shown in figure 78, is the basis of our measurement of time. The earth revolving on its axis completes one revo-

lution each day or 24 hours. Another way of stating this would be that the sun passes each meridian once each day. For uniformity the meridian of Greenwich, England, has been selected as the prime meridian from which time is measured and the moment the sun crosses this meridian it is noon of that date. Being noon at Greenwich, it then must be midnight at the 180th meridian exactly opposite it. Since the calendar day starts at midnight the new day actually commences at the 180th meridian.

Noon being the moment the sun crosses the meridian, it follows that it can be noon at only one meridian at any one instant, and since the sun appears to travel from east to west, any place west of Greenwich will have its noon later than Greenwich by an interval equal to the angular distance the sun has to travel to get to the meridian of that place. Since this angular distance is longitude, it is apparent that a

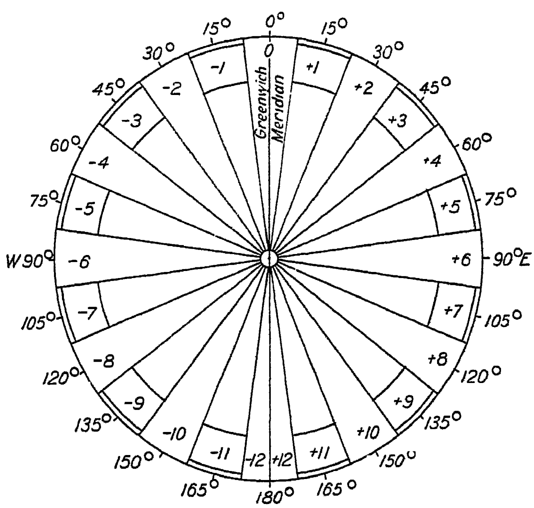

FIGURE 79.—Zone time diagram.

definite relation exists between time and longitude. Thus, if the Greenwich time is known, and the longitude of any place is known, the sun time at that place can be found by adding or subtracting the longitude of the place to the Greenwich time. For convenience the world is divided into 24 zones of 15° or 1 hour each, as shown in figure 79, and the time of each zone designated by the time of its midmeridian. Each zone is designated by the number of hours its time differs from Greenwich time. Zones in west longitude are prefixed plus and zones in east longitude are prefixed minus. Pensacola, Fla., is in zone plus 6, as that figure must be added to the standard time at Pensacola to obtain Greenwich civil time. Zone time is called standard time and is that by which our daily lives are regulated.

Greenwich civil time is merely the standard time at Greenwich. The hours are numbered consecutively from 0 to 24 instead of being denoted by a. m. and p. m. The navigator must have, or be able to determine, the Greenwich civil time of all celestial observations.

Thus far only the rotation of the earth has been considered. If this were the only motion possessed by the earth, time would be uniform and each day identical. Actually, however, the earth does not rotate in one place in the universe but travels in an ellipse about the sun. Since the earth moves at a uniform speed it will be apparent that the angular speed at the long axis of the ellipse is less than when it is at the short axis. This variation in angular speed causes an uneven rate to be imparted to the sun which makes the time of each day vary by a small amount. In order to have a time which clocks can keep, an imaginary sun has been devised which is supposed to travel at a uniform angular speed in the equinoctial. The difference between time kept by chronometers (imaginary sun) and that measured by the real sun has been computed by astronomers and called the *equation of time*. It is tabulated in the Nautical Almanac for 2-hour intervals.

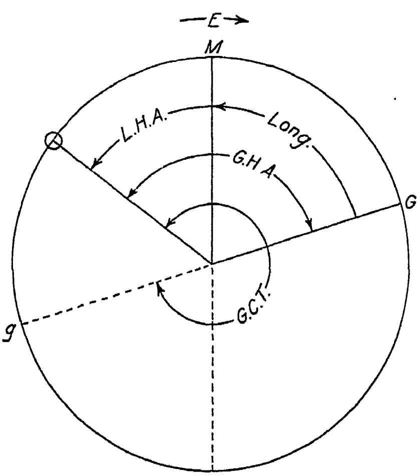

FIGURE 80.—Time and longitude diagram.

Sidereal time.—The earth actually makes 366.24 rotations each year. Because it travels once around the sun during this period, it loses a day, and the earth thus has but 365.24 days each year. For a star at an infinite distance from the earth's orbit, the earth would seem to have 366.24 days. For stars, time would have to be reckoned on a different basis. The point in space called the *vernal equinox* is used as the reference point for star or sidereal time. For navigation, sidereal time is no longer of primary importance, since the astronomers have computed its relation to sun time and defined the location of the most important navigational stars by means of the Greenwich meridian.

Time diagram.—In order to get an accurate picture of the relation between longitude and time a simple diagram has been devised. If the observer stood at the south pole and looked down at the equator the meridians would appear as straight lines. If the meridian of a

place is *PM*, then *PG*, the Greenwich meridian, can be drawn with *MG* equal to the longitude. Then if the sun's meridian is drawn, *SG* would be equal to the Greenwich hour angle, while *SM* equals the local hour angle. This local hour angle is of primary interest to the navigator, since it forms one of the elements of the celestial triangle. It can be seen that if the sun is to the westward of the Greenwich meridian the *LHA* would then be the difference of the place's longitude and the angle between the Greenwich meridian and that of the sun.

Finding Greenwich time and date.—The solution of nearly every problem in celestial navigation requires reference to data contained in the Nautical Almanac. These data are tabulated for various celestial bodies in such a way that it may be found for any instant of Greenwich civil time. It becomes essential, therefore, that the navigator become thoroughly familiar with the method of finding the Greenwich civil time and date.

The first operation necessary is to deduce from a knowledge of the approximate zone time and longitude, the corresponding Greenwich date and approximate time expressed in hours, from 0 to 24. This is essential since a chronometer dial is usually marked from 0 to 12 hours, and may, therefore, be 12 hours in error on the astronomical time used in the almanac. If the approximate Greenwich civil time shows it to be afternoon in Greenwich, 12 hours must be added to the chronometer reading.

Remembering that west longitudes are positive and east longitudes are negative, we have the following rule for converting zone to Greenwich time:

GCT=Zone time+zone description.

HOUR ANGLE

The *local hour angle* is the difference in longitude between the meridian of an observer and the hour circle through the substellar or subsolar point. If the Greenwich hour angle can be determined, the local hour angle may be readily found by combining this value with the longitude. The Nautical Almanac lists the Greenwich hour angle of the sun for every 2 hours, of the moon for every hour, and of the 4 navigational planets, and 55 navigational stars for 0 hours of each day. If the exact time for which the hour angle is desired is not tabulated, it must be found by interpolation, for which tables are provided in the Nautical Almanac. The following examples illustrate the interpolation method of finding the G. H. A. for the different bodies.

Extracts from the "Nautical Almanac, 1939", for use in examples and problems, are given at the end of the chapter.

Example 1.—February 25, 1939, G. H. A. of the sun for G. C. T., $13^h20^m31^s$.

(*a*) Enter sun table with date and with G. C. T. to nearest hour and take out G. H. A.

(*b*) Obtain the correction for minutes, or 1 hour plus minutes from small section headed "Corr. to G. H. A." This correction table is on every other page.

(*c*) Obtain the correction for seconds from the same section.

(*d*) The sum of the three quantities is the G. H. A. for the given G. C. T. thus:

G. H. A. 12^h	356°40′.5
Corr. 1^h20^m	20°00′.0
Corr. 31^s	7′.8
G. H. A.	376°48′.3 W.
Subtract 360°	16°48′.3 W.

Example 2.—June 10, 1939, G. H. A. of the moon for G. C. T. $07^h28^m42^s$.

(*a*) Enter moon tables with date and nearest G. C. T. and take out G. H. A. for this tabulated hour.

(*b*) Obtain correction for minutes from auxiliary table under heading "Multiples of variation per minute."

(*c*) Obtain correction for seconds from same table. The correction for 1 minute or 60 seconds is given. The correction for the given number of seconds is the result obtained by multiplying the correction for 1 minute by the given number of seconds and dividing by 60.

(*d*) The sum of the above quantities is the G. H. A. for the given G. C. T.

G. H. A.	7^h,	13°34′.8
Corr.	20^m, (291′.4)	4°51′.4
Corr.	8^m, (116′.5)	1°56′.5
Corr.	42^s, $\frac{42\times14'.6}{60}$	10′.2
G. H. A.		20°32′.9 W.

Example 3.—January 1, 1939. Required the G. H. A. of the planet Jupiter for $20^h14^m18^s$.

(*a*) Enter planet table for Jupiter with date and take out G. H. A. for 0 hours and note "variation per minute."

(*b*) Obtain corrections for hours, minutes, and seconds from separate tables at end of planet section, using given time and variation of hour angle per minute as arguments. Each table is headed "Cor-

rection to be added to tabulated Greenwich hour angle of Planets." The correction for seconds is based on a variation of hour angle of 15′ per minute for all planets.

(*c*) The sum of the tabulated G. H. A. and the corrections is the G. H. A. for the given G. C. T.

G. H. A.	0^h	126°53′.0	Var. per min. 15′.0334.
Corr.	20^h	300°40′.1	
Corr.	14^m	3°30′.5	
Corr.	18^s	4′.5	
G. H. A.		431°08′.1 W.	
or subtract 360°			
		71°08′.1 W.	

Example 4.—October 1, 1939. Required the G. H. A. of the star Vega for

G. C. T. $04^h43^m23^s$.

(*a*) Enter star table for October with Greenwich date and under column headed Vega take out G. H. A. for 0 hours.

(*b*) Obtain correction for hours and minutes from table headed "Correction to be added to tabulated Greenwich hour angle of stars" at end of star tables.

(*c*) Obtain correction for seconds from table on same page as above correction.

(*d*) The sum of the three quantities is the G. H. A. for the given G. C. T.

G. H. A.	0^h	90°06′.1
Corr.	4^h43^m,	70°56′.6
Corr.	23^s	5′.8
G. H. A.		161°08′.5

The process of combining the Greenwich hour angle and longitude to obtain the local hour angle may best be determined from a time diagram. In figure 81 the circle represents the equator and *P* the pole. *PM* is the observer's meridian. *PG*, the Greenwich meridian, is obtained by measuring from *M* a distance equal to the longitude in the opposite direction to the name of the longitude. The star *S* is located by measuring from *G* always to the westward a distance equal to the G. H. A. The length of the arc *MS* is the local hour angle east of the meridian. The value of the local hour angle, as tabulated in navigational tables, is never more than 180° and is measured either east or west of the meridian. In figure 81, the longitude is 60° E, the G. H. A. is 240° W. the L. H. A. is 300° W. or 60° E.

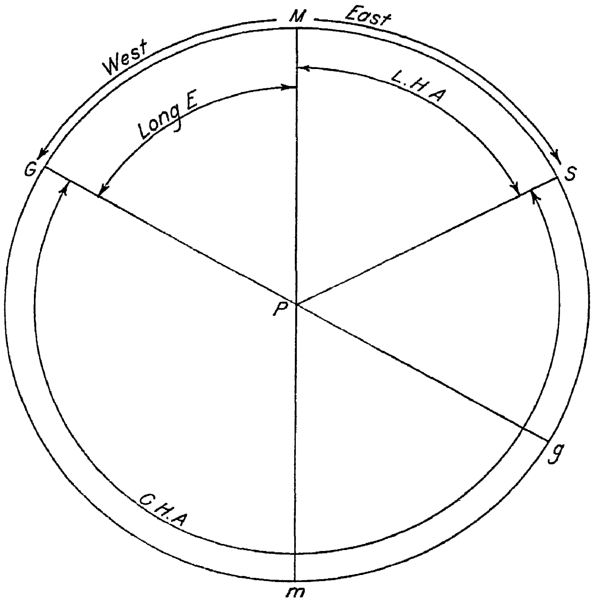

FIGURE 81.—Time diagram for determining local hour angle.

PROBLEMS

(Answers to problems will be found at end of chapter)

1. Find the L. H. A. of the sun:
   (a) February 28, 1939, G. C. T. $12^h23^m11^s$, long. 77°10′.0 W.
   (b) February 25, 1939, G. C. T. $01^h12^m56^s$, long. 138°12′.5 W.
   (c) February 27, 1939, G. C. T. $11^h45^m23^s$, long. 30°14′.6 W.
   (d) February 26, 1939, G. C. T. $16^h37^m49^s$, long. 91°55′.0 W.
   (e) February 27, 1939, G. C. T. $04^h54^m32^s$, long. 150°10′.0 E.
2. Find the L. H. A. of the moon:
   (a) June 12, 1939, G. C. T. $10^h32^m16^s$, long. 80°13′.0 W.
   (b) June 10, 1939, G. C. T. $19^h27^m32^s$, long. 141°15′.8 W.
   (c) June 13, 1939, G. C. T. $08^h56^m54^s$, long. 33°17′.9 W.
   (d) June 11, 1939, G. C. T. $17^h48^m23^s$, long. 94°58′.3 W.
   (e) June 10, 1939, G. C. T. $02^h13^m45^s$, long. 147°13′.0 E.
3. Find the L. H. A. of Jupiter:
   (a) January 5, 1939, G. C. T. $18^h21^m05^s$, long. 86°19′.0 W.
   (b) March 21, 1939, G. C. T. $10^h17^m13^s$, long. 147°21′.0 W.
   (c) February 9, 1939, G. C. T. $10^h32^m07^s$, long. 39°28′.0 W.
   (d) March 8, 1939, G. C. T. $08^h31^m11^s$, long. 100°38′.5 W.
   (e) January 11, 1939, G. C. T. $19^h16^m13^s$, long. 140°43′.5 E.
4. Find the L. H. A. of the following stars:
   (a) Vega, October 31, 1939, G. C. T. $05^h30^m10^s$, long. 65°08′.5 W.
   (b) Peacock, October 17, 1939, G. C. T. $07^h17^m23^s$, long. 126°50′.0 W.
   (c) Markab, October 29, 1939, G. C. T. $01^h09^m42^s$, long. 18°31′.0 W.
   (d) Nunki, October 8, 1939, G. C. T. $02^h16^m04^s$, long. 79°21.0 W.
   (e) Deneb, October 5, 1939, G. C. T. $04^h27^m52^s$, long. 138°42′.0 E.

DECLINATION

The declination of celestial bodies is found from the Nautical Almanac as illustrated by the following examples:

Example 1.—February 25, 1939. Required the declination of the sun for G. C. T. $13^h20^m31^s$.

(*a*) Enter sun table with date and nearest G. C. T. and take out declination.

(*b*) Correct the declination for the time elapsed since even numbered hour. The change in declination per hour (H. D.) is listed for each day for convenience in interpolating.

(*c*) Mark the declination north or south. A plus sign (+) in the table indicates north and a minus sign (−) south declination.

Dec. 12^h	9°18′.9 S.	H. D.	′.9
Corr. $1^h20.5^m$	−1′.2	Corr. 20.5^m	′.3
Dec.	9°17′.7 S.	Total corr.	−1′.2

Example 2.—June 10, 1939. Required the declination of the moon for G. C. T. $07^h28^m42^s$.

(*a*) Enter moon table with date and G. C. T. and take out declination for given hour.

(*b*) Correct the declination for time elapsed since given hour by means of small table "Multiples of variation per minute."

(*c*) Mark the declination north or south.

Dec. 7^h	0°29′.7 S.	Corr. 20^m	3′.4
Total corr.	−4′.8	Corr. 8^m	1′.3
		Corr. 42^s	′.1
Dec.	0°24′.9 S.		
		Total corr.	−4′.8

Example 3.—January 1, 1939. Required the declination of the planet Jupiter for G. C. T. $20^h14^m18^s$.

(*a*) Enter Jupiter table with Greenwich date and take out declination for 0 hours of that date.

(*b*) Correct the declination for time elapsed since 0 hours. The change in declination for 24 hours is tabulated in small numbers between dates.

(*c*) Mark the declination north or south.

Dec. 0^h	12°16′.2 S.	Change in 24^h=4′.2
Corr.	−3′.5	Change in $20^h14^m18^s$= −3′.5
Dec.	12°12′.7 S.	

Example 4.—October 1, 1939. Required declination of the star Vega for G. C. T. $04^h43^m23^s$.

172649—40——11

The change in declination for stars is so small that declination is tabulated in the hour angle table for stars for the first of each month only. Ordinarily, the value is used for the nearest first of the month.

(*a*) Enter the star tables for month of October and under the column headed Vega take out declination and mark it north or south. Dec. 38°44′.0 N.

PROBLEMS

5. Find the declination of the sun:
   - (*a*) February 28, 1939, G. C. T. $13^h33^m16^s$.
   - (*b*) February 25, 1939, G. C. T. $02^h22^m51^s$.
   - (*c*) February 27, 1939, G. C. T. $12^h55^m28^s$.
   - (*d*) February 26, 1939, G. C. T. $17^h47^m54^s$.
   - (*e*) February 27, 1939, G. C. T. $05^h44^m37^s$.
6. Find the declination of the moon:
   - (*a*) June 12, 1939, G. C. T. $12^h34^m18^s$.
   - (*b*) June 10, 1939, G. C. T. $21^h29^m34^s$.
   - (*c*) June 13, 1939, G. C. T. $10^h58^m56^s$.
   - (*d*) June 11, 1939, G. C. T. $19^h50^m23^s$.
   - (*e*) June 10, 1939, G. C. T. $04^h15^m47^s$.
7. Find the declination of Jupiter:
   - (*a*) March 5, 1939, G. C. T. $22^h27^m52^s$.
   - (*b*) February 27, 1939, G. C. T. $20^h00^m24^s$.
   - (*c*) January 19, 1939, G. C. T. $18^h03^m06^s$.
   - (*d*) March 22, 1939, G. C. T. $19^h12^m50^s$.
   - (*e*) February 13, 1939, G. C. T. $10^h17^m31^s$.
8. Find the declination of the following stars:
   - (*a*) Vega, October 7, 1939, G. C. T. $18^h39^m30^s$.
   - (*b*) Peacock, October 12, 1939, G. C. T. $12^h26^m50^s$.
   - (*c*) Fomalhaut, October 10, 1939, G. C. T. $23^h31^m02^s$.
   - (*d*) Markab, October 15, 1939, G. C. T. $12^h59^m59^s$.
   - (*e*) Nunki, October 3, 1939, G. C. T. $21^h48^m00^s$.

AZIMUTH

Azimuth is the true bearing of the geographic position of a celestial body from the assumed position of the observer; or, it is the true bearing of a celestial body from the north point of the horizon measured at the zenith of the assumed position of the observer. True azimuth is always measured from 0° at north around to the right through 360°. The tables used in finding the azimuth give the values from 0° to 180° east or west of the meridian and westerly values must be converted to read from 180° to 360°. The value of the azimuth as determined by logarithmic tables give results up to 90° or 180° and must be converted so that the true azimuth reads from north through 360°. Z^n represents true azimuth, Z represents the angle. The rules for determining true azimuth for most tables are given below:

(All values are from the elevated pole.)

North Latitude.—When the local hour angle is east the value of the azimuth as found in the tables is the true azimuth. When the local hour angle is west subtract the value of the azimuth as found in the tables from 360° to get the true azimuth.

South Latitude.—When the local hour angle is east subtract the value of the azimuth as found in the tables from 180° to get the true azimuth. When the local hour angle is west add 180° to the value of the azimuth as found in the tables to get the true azimuth.

Thus in north latitude the value of the azimuth in the tables is the angle between true north and the celestial body but if the body is west of the observer's meridian, it is the value from north to west, instead of clockwise as true bearing through 360° is measured. In south latitude the value in the tables is the angle from the south pole and this value must be combined with 180° to get the true bearing from north.

ALTITUDE

The true altitude (*Ho*) of a celestial body at any place on the earth's surface is the altitude of its center as it would be measured by an observer at the center of the earth. The observed altitude (*Hs*) of an observed body is not the true altitude. Several corrections are necessary. The corrections to be made depend upon the type of instrument used as well as upon the particular celestial body observed.

In general the corrections that must be applied are as follows:

(*a*) *Index correction—I. C.*—a correction that must be applied because the instrument is reading inaccurately either too high or too low.

This correction must be determined for each instrument.

(*b*) *Dip.*—For an observation from the natural horizon a correction for height of eye must be made. As the height of eye of an observer increases, the horizon dips, and the measured altitude must be corrected for the amount of this dip.

(*c*) *Refraction.*—When rays of light pass obliquely from one medium into another of different density, a deviation in the course of the rays occurs. This bending of the rays is called refraction and causes the measured altitude to read greater than the true altitude.

(*d*) *Parallax.*—An observation of a celestial body is made on the earth's surface; in order to reduce this altitude to what it would read at the center of the earth, a correction for parallax is made.

(*e*) *Semidiameter.*—In making an observation of the sun or moon the altitude of the bottom or top of the disc is usually measured, and the semidiameter is applied to get the altitude of the body's center.

The above corrections are combined and tabulated in the Nautical Almanac, for it is not necessary to make each correction separately. The corrections necessary for altitudes measured from the visible horizon are not the same as those for an altitude measured from the horizontal as established by a bubble. The following examples illustrate the corrections for both types of altitude.

Corrections for altitudes measured from the visible horizon:

Example 1. Sun.—February 25, 1939. Required the true altitude of the sun. *Hs* (lower limb) 32°08′.0, I. C. (+)2′.0, height of eye 30 feet.

Hs	32°08′.0	I. C.	(+) 2′.0
corr.	(+)11′.4	Table A	(+)14′.6
		Table B	(+) 0′.2
Ho	32°19′.4	Table C	(−) 5′.4
		corr.	(+)11′.4

Table A corrects for refraction, parallax, and semidiameter. Table B is an additional correction for semidiameter for the sun only on different dates. Table C corrects for dip.

Example 2. Moon.—June 10, 1939. Required the true altitude of the moon, G. C. T. $07^h30^m00^s$, *Hs* (lower limb) 45°20′.0, I. C. 0′.0, height of eye 60 feet.

Horizontal parallax from Nautical Almanac is 54′.6.

Hs	45°20′.0	I. C.	0′.0
corr.	(+)44′.8	Table C	(−) 7′.6
		Table D	(+)52′.4
Ho	46°04′.8		
		corr.	(+)44′.8

Table C corrects for dip. The horizontal parallax of the moon is taken from the Nautical Almanac for date and G. C. T. and with *Hs* form the arguments for entering table D. Table D corrects parallax, refraction, and semidiameter. Note that the table is in two parts, one for an observation of the lower limb, the other for an observation of the upper limb.

Example 3. Star.—October 1, 1939. Required the true altitude of the star Vega, at G. C. T. $17^h20^m30^s$, *Hs* 53°30′.0, I. C. (−)1′.0, height of eye 1,000 feet.

Hs	53°30′.0	I. C.	(−) 1′.2
corr.	(−)32′.7	Table A	(−) 0′.7
		Table C	(−)31′.0
Ho	52°57′.3		
		corr.	(−)32′.7

Table A corrects for refraction. There is no appreciable correction for parallax or semidiameter. Table C corrects for dip.

Example 4. Planet.—August 1, 1939. Required the true altitude of Jupiter, G. C. T. at $9^h20^m10^s$, *Hs* 62°22′.0, I. C. (−) 1′.2, height of eye 1,800 feet.

Hs	62°22′.0	I. C.	(−) 1′.2
corr.	(−)43′.4	Table A	(−) 0′.6
		Table C	(−)41′.6
Ho	61°38′.6		
		corr.	(−)43′.4

The corrections for a planet are identical with those of a star, and are found in the same tables.

PROBLEMS

9. Given the following altitudes of the lower limb of the sun measured from the horizon, find the true altitude.

(*a*) January 5, 1939. *Hs* 71°10′.0, I. C. (+) 1′.2, height of eye 2,400 feet.

(*b*) May 10, 1939. *Hs* 37°29′.0, I. C. (−) 2′.5, height of eye 15 feet.

(*c*) September 20, 1939. *Hs* 52°54′.0, I. C. (+) 2′.0, height of eye 500 feet.

10. Given the following altitudes of the lower limb of the moon measured from the horizon, find the true altitude.

(*a*) June 10, 1939, at 0600. *Hs* 31°20′.0, I. C. (−) 1′.0, height of eye 3,000 feet.

(*b*) June 12, 1939, at 1200. *Hs* 27°36′.0, I. C. 0′.0, height of eye 30 feet.

(*c*) June 11, 1939, at 1800. *Hs* 42°54′.0, I. C. (+) 1′.5, height of eye 600 feet.

11. Given the following altitudes of a star measured from the horizon, find the true altitude.

(*a*) *Hs* 23°32′.8, I. C. (+) 0′.8, height of eye 1,025 feet.

(*b*) *Hs* 56°05′.0, I. C. 0′.0, height of eye 47 feet.

(*c*) *Hs* 74°47′.0, I. C. (−) 1′.2, height of eye 3,350 feet.

12. Given the following altitudes of a planet measured from the horizon, find the true altitude.

(*a*) *Hs* 32°14′.0, I. C. (+) 1′.2, height of eye 10 feet.

(*b*) *Hs* 65°56′.0, I. C. 0′.0, height of eye 45 feet.

(*c*) *Hs* 47°23′.0, I. C. (−) 0′.8, height of eye 1,250 feet.

When using a bubble octant for making observations of celestial bodies, dip and semidiameter are eliminated. The errors to be corrected are the instrument error and the error due to refraction and parallax. The instrument correction is usually on a card that comes with the instrument. The correction for parallax and refraction is in table E of the Nautical Almanac for the sun, stars, and planets, and in table F for the moon.

Corrections for altitudes measured with a bubble octant:

Example 1. Sun.—Find the true altitude of the sun, *Hs* 32°10′.5, I. C. (+) 1′.0.

		I. C.	(+) 1′.0
Hs	32°10′.5	Table E	(−) 1′.4
corr.	(−) 0′.4		
		corr.	(−) 0′.4
Ho	32°10′.1		

Example 2. Moon.—June 10, 1939. Find the true altitude of the moon, G. C. T $07^h30^m40^s$, *Hs* 34°30′.0, I. C. (−) 1′.0. Horizontal parallax from Nautical Almanac 54′.6.

Hs	34°30′.0	I. C.	(−) 1′.0
corr.	(+) 42′.6	Table F	(+) 43′.6
Ho	35°12′.6	corr.	(+) 42′.6

Example 3. Star.—Find the true altitude of the star Vega, *Hs 47°15′.0, I. C.* (+) 1′.0.

Hs	47°15′.0	I. C.	(+) 1′.0
corr.	(+) 0′.1	Table E	(−) 0′.9
Ho	47°15′.1	corr.	(+) 0′.1

Example 4. Planet.—Find the true altitude of the planet Jupiter, *Hs* 52°45′.0, I. C. (−) 3′.0.

Hs	52°45′.0	I. C.	(−) 3′.0
corr.	(−) 3′.7	Table E	(−) 0′.7
Ho	52°41′.3	corr.	(−) 3′.7

PROBLEMS

13. Given the following bubble octant altitudes of the sun, find the true altitude.
(*a*) *Hs* 67°10′.0, I. C. (+) 2′.2.
(*b*) *Hs* 32°25′.0, I. C. 0′.0.
(*c*) *Hs* 47°50′.0, I. C. (−) 1′.7.

14. Given the following bubble octant altitudes of the moon, find the true altitude.
(*a*) June 12, 1939, at 0600. *Hs* 59°18′.0, I. C. (−) 1′.1.
(*b*) June 10, 1939, at 1800. *Hs* 25°36′.0, I. C. (+) 0′.5.
(*c*) June 11, 1939, at 1200. *Hs* 40°48′.0, I. C. (−) 0′.4.

15. Given the following bubble octant altitudes of a star, find the true altitude.
(*a*) *Hs* 33°35′.0, I. C. (−) 2′.1.
(*b*) *Hs* 66°05′.0, I. C. (+) 1′.5.
(*c*) *Hs* 84°45′.0, I. C. (−) 1′.4.

16. Given the following bubble octant altitudes of a planet, find the true altitude.
(*a*) *Hs* 38°15′.0, I. C. (+) 0′.8.
(*b*) *Hs* 71°55′.0, I. C. 0′.0.
(*c*) *Hs* 53°30′.0, I. C. (−) 1′.2.

SOLUTIONS OF THE ASTRONOMICAL TRIANGLE

After the approximate local hour angle and declination of a celestial body have been determined, the altitude and azimuth are computed by solving the astronomical triangle. As the astronomical triangle is merely a spherical triangle on the surface of the celestial

sphere, it may be solved by spherical trigonometry. However, in order to reduce the time required for solution, special tables have been devised. In some of the tables the dead-reckoning position is used; in others an assumed position is selected. Each method has an explanation and description of the use of its tables. To use any method, it is only necessary to follow the instructions that are a part of the method. The Hydrographic Office issues the following publications of particular interest to the aerial navigator for use in celestial navigation.

H. O. 208—Navigation Tables for Mariners and Aviators (Dreisonstok.)—In this method the navigator assumes such a latitude and longitude that the latitude and local hour angle are both integral degrees of arc. The assumed position should be selected near to the dead-reckoning position. The resulting line of position is plotted from the chosen assumed position.

H. O. 211—Dead Reckoning, Altitude, and Azimuth Tables (Ageton).—Sights are solved generally from the dead-reckoning position, but the sight may be solved from any other assumed position. The line of position is then plotted from the chosen latitude and longitude.

H. O. 214—Tables of Computed Altitude and Azimuth (in 9 volumes).—These tables consist essentially of tabulated solutions of the astronomical triangle, so arranged as to yield the navigator his calculated altitude and azimuth by inspection.

The scheme of precomputing such values for ready use is a long established one; it is in scope, arrangement, and convenience of interpolation that these tables are unique.

There are no precepts connected with the use of the tables.

The tables are applicable equally to sights of the sun, moon, planets, and navigational stars; and inasmuch as they are designed for use in connection with celestial bodies of declinations both of same name as, and contrary name to the latitude, they apply to both northern and southern hemispheres.

For greater convenience in use, the values for 10° of latitude are included in a single volume.

Solution by H. O. 211.—Figure 82 shows a sample example worked on a form designed for use with H. O. 211. A blank form for the solution of a sight is not absolutely necessary, but it does reduce the solution to a routine operation.

Opposite G. C. T. is entered the Greenwich civil time and date of the observation. The G. H. A. and corrections are taken from the Nautical Almanac as previously explained. The longitude of the dead reckoning or assumed position is then combined with the G. H. A. for the L. H. A. A time diagram in the left-hand circle

shows how the two are to be combined. The L. H. A. must be less than 180° and marked E. or W. The octant altitude is corrected and the true altitude entered at *Ho.*

In the left-hand column, opposite Dec. is the declination obtained from the Nautical Almanac and marked N. or S. Opposite Lat. is the dead reckoning or assumed latitude and marked N. or S. *Ho* is filled in with the true altitude previously determined.

The remainder of the form is filled in with values from H. O. 211. An *A* on the form indicates values from the *A* columns of the tables and *B* indicates values from the *B* columns. When a number does

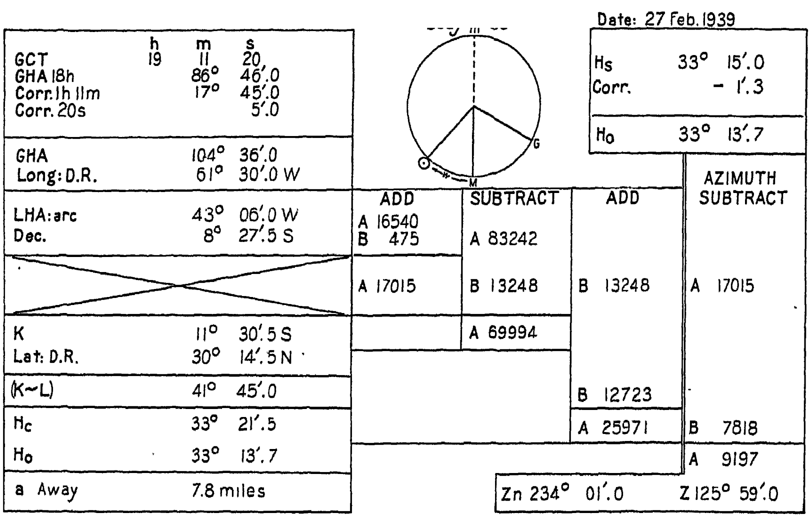

FIGURE 82.—Solution by H. O. 211.

not appear exactly in the tables, the nearest tabulated number is used. No interpolation is made in the tables. Extracts from H. O. 211 necessary for this example are shown in the accompanying table.

Extracts from H. O. 211:

		B			*B*
43°06′.0	16540	13658	41°45′.0	17660	12723
8°27′.5	83242	475	33°21′.5	25974	7818
	17018	13248	33°22′.0	25964	7823
	17011	13254	125°59′.5	9200	23087
11°30′.5	70003	882	125°59′.0	9195	23095
11°31′.0	69972	833			

The *A* value for a L. H. A. of 43°06′ is copied from the tables and entered on the form in the space provided.

Next the *B* value for a declination of 8°27′.5 is copied in the space indicated and the corresponding *A* value is entered at *A*.

As indicated on the form the first column is *added* to get an A value of 17015. Find this number, or the nearest tabulated value, in the tables and take out the corresponding B value which is entered on the form in columns 2 and 3. The A value is repeated in column 4.

Subtract column 2 as indicated for an A value of 69994. From the tables find the degrees and minutes corresponding to this value and enter on the form at K. K is taken from the bottom or top of the column in accordance with the rule at the top of the left-hand pages.

Give K the same name (N. or S.) as the declination. Combine K with Lat. to obtain $K \sim L$, adding K and Lat. if different names and substracting the smaller from the larger if the names are the same.

The B value for $K \sim L$ is entered on the form in column 3 and the required *addition* performed. Enter the tables with the A value thus obtained and copy the corresponding B value in column 4. The degrees and minutes from the top of the table for the A value are entered on the form opposite Hc.

"a" is the altitude intercept or the difference between Ho and Hc. It is marked "away" when Hc is greater and marked "toward" when Ho is greater.

Next *subtract* as indicated in the fourth column for an A value of 9197. The corresponding value for this A in degrees and minutes is entered opposite Z. The value of Z is taken from the tables in accordance with the rule at the top of the right hand pages.

Zn is obtained from Z by the rules previously given under "Azimuth."

Solution by H. O. 214.—The latest tables for solving navigational sights are in H. O. 214. These tables are meant to be used primarily with a position so assumed that the latitude and hour angle are in integral degrees. When this is done it is only necessary to correct for the difference between the true declination of a celestial body and the nearest tabulated value.

The following description is taken practically verbatim from H. O. 214.

The tables are equally applicable to sights of the sun, moon, planets, and stars.

The arrangement is on a basis of whole degrees of latitude, the data for each degree comprising a section of 24 pages, with 2 additional pages for star identification.

Declination arguments in whole and half degrees head the main columns of each page, while hour angle arguments in whole degrees appear at the sides. In each declination column are four groups

of figures representing, from left to right—the altitude (Alt.); the multiplier, Δd, for declination difference; the multiplier, Δt, for hour angle difference; and the azimuth (Az.).

Δd represents the change in altitude due to a change of 1′ of arc of declination. Δt represents the change in altitude due to a change of 1′ of arc of hour angle. Δt is used only when it is desired to plot from the dead-reckoning longitude.

The altitude obtained from the tables is correct for the values with which the tables are entered; but since the exact declination of the body will usually differ from the tabulated declination, a correction to the altitude must be made for this difference. For example, if the exact declination of a star is 8°33′.1 and the table is entered with a declination of 8°30′.0, the declination difference is 3′.1. Since Δd is the change in altitude due to a change of 1′ of declination, Δd multiplied by the declination difference is the correction to be applied to the tabulated altitude to get the correct altitude for the given declination.

From a table on the inside back cover the values of Δd multiplied by the declination difference may be obtained. The table is entered with Δd at the side and declination difference at the top, and the correction to the altitude taken from the body of the table. The table is in two parts, one for whole numbers of declination difference and the other for tenths of declination difference.

The correction is added to the tabulated altitude if the altitude is increasing as the tabulated declination approaches the exact declination. The correction is subtractive if the altitude is decreasing as the tabulated declination approaches the exact declination.

The tabulated azimuth must be changed into true azimuth in accordance with the rules previusly given under "Azimuth." It is not necessary to interpolate for the azimuth. It is correct enough for plotting lines of position.

When only the Δd correction is made the sight must be plotted from an assumed position as follows:

Latitude—the integral degree with which the tables are entered.

Longitude—the longitude which was assumed in finding the local hour angle in integral degrees.

The same example illustrated under "Solution by H. O. 211" is solved below by H. O. 214.

DECLINATION **CONTRARY** NAME TO LATITUDE

H.A.	8° 00′ Alt.			8° 00′ Az.	8° 30′ Alt.			8° 30′ Az.
°	° ′	Δd	Δt	°	° ′	Δd	Δt	°
00	52 00.0	1.0	01	180.0	51 30.0	1.0	01	180.0
1	51 59.3	1.0	04	178.4	51 29.3	1.0	04	178.4
2	51 57.1	1.0	06	176.8	51 27.1	1.0	06	176.8
3	51 53.5	99	09	175.2	51 23.5	99	09	175.2
4	51 48.4	99	11	173.6	51 18.5	99	11	173.6
05	51 41.9	99	13	172.0	51 12.1	99	13	172.1
6	51 33.9	99	16	170.4	51 04.2	99	15	170.5
7	51 24.6	99	18	168.8	50 55.0	99	18	169.0
8	51 13.8	98	20	167.3	50 44.4	98	20	167.5
9	50 01.7	97	23	165.7	50 32.5	98	22	165.9
10	50 48.2	97	25	164.2	50 19.1	97	25	164.4
1	50 33.4	97	27	162.7	50 04.4	97	27	162.9
2	50 17.3	96	29	161.2	49 48.5	96	29	161.4
3	49 59.9	95	31	159.7	49 31.3	95	31	160.0
4	49 41.3	95	33	158.3	49 12.9	95	33	158.6
15	49 21.5	94	35	156.8	48 53.3	94	35	157.1
6	49 00.4	93	37	155.4	48 32.5	93	37	155.7
7	48 38.2	92	39	154.0	48 10.5	92	39	154.3
8	48 14.9	92	41	152.6	47 47.4	92	40	152.9
9	47 50.5	91	43	151.3	47 23.2	91	42	151.6
20	47 25.0	90	44	150.0	46 58.0	90	44	150.3
1	46 58.5	89	46	148.7	46 31.8	90	46	149.0
2	46 31.0	88	48	147.4	46 04.5	89	47	147.8
3	46 02.5	87	49	146.1	45 36.3	88	49	146.5
4	45 33.0	86	51	144.9	45 07.1	87	50	145.3
25	45 02.7	86	52	143.7	44 37.0	86	52	144.1
6	44 31.5	85	53	142.5	44 06.1	85	53	142.9
7	43 59.5	84	54	141.3	43 34.3	84	54	141.7
8	43 26.6	83	56	140.2	43 01.7	83	56	140.6
9	42 52.9	82	57	139.1	42 28.3	82	57	139.5
30	42 18.5	81	59	138.0	41 54.1	81	58	138.4
1	41 43.4	81	60	136.9	41 19.2	81	59	137.2
2	41 07.5	80	61	135.8	40 43.6	80	60	136.2
3	40 30.9	79	62	134.8	40 07.4	79	62	135.2
4	39 53.8	78	63	133.8	39 30.4	78	63	134.2
35	39 15.9	77	64	132.8	38 52.8	77	64	133.2
6	38 37.5	76	65	131.8	38 14.7	76	65	132.2
7	37 58.6	75	66	130.9	37 36.0	75	66	131.3
8	37 19.0	74	67	130.0	36 56.7	75	67	130.4
9	36 38.9	74	68	129.0	36 16.8	74	67	129.5
40	35 58.2	73	69	128.1	35 36.4	73	68	128.6
1	35 17.1	72	69	127.2	34 55.5	72	69	127.7
2	34 35.5	71	70	126.4	34 14.1	71	70	126.8
3	33 53.5	71	71	125.6	33 32.3	71	70	126.0
4	33 11.0	70	72	124.7	32 50.1	70	71	125.2

MULTIPLICATION TABLE

Dec. diff. or H. A. diff. (minutes of arc),

Δ	1′	2′	3′	4′	5′	6′
65	0. 7	1. 3	2. 0	2. 6	3. 3	3. 9
6	. 7	1. 3	2. 0	2. 6	3. 3	4. 0
7	. 7	1. 3	2. 0	2. 7	3. 4	4. 0
8	. 7	1. 4	2. 0	2. 7	3. 4	4. 1
9	. 7	1. 4	2. 1	2. 8	3. 5	4. 1
70	0. 7	1. 4	2. 1	2. 8	3. 5	4. 2
1	. 7	1. 4	2. 1	2. 8	3. 6	4. 3
2	. 7	1. 4	2. 2	2. 9	3. 6	4. 3
3	. 7	1. 5	2. 2	2. 9	3. 7	4. 4
4	. 7	1. 5	2. 2	3. 0	3. 7	4. 4

Dec. diff. or H. A. diff. (tenths of minutes)

Δ	0.1′	0.2′	0.3′	0.4′	0.5′	0.6′
65	0. 1	0. 1	0. 2	0. 3	0. 3	0. 4
6	. 1	. 1	. 2	. 3	. 3	. 4
7	. 1	. 1	. 2	. 3	. 3	. 4
8	. 1	. 1	. 2	. 3	. 3	. 4
9	. 1	. 1	. 2	. 3	. 3	. 4
70	0. 1	0. 1	0. 2	0. 3	0. 4	0. 4
1	. 1	. 1	. 2	. 3	. 4	. 4
2	. 1	. 1	. 2	. 3	. 4	. 4
3	. 1	. 1	. 2	. 3	. 4	. 4
4	. 1	. 1	. 2	. 3	. 4	. 4

G. C. T. $19^h11^m20^s$, February 27.
G. H. A. 86°46′.0
corr. 17°45′.0
corr. 5′.0

G. H. A. 104°36′.0 W.

Hs		33°15′.0
I. C.		0′.0
Table E	(—)	1′.3
Ho		33°13′.7

Long. *61°36′.0 W*. (assumed so that L. H. A. will be an integral degree).

L. H. A. 43°00′.0 W.

Lat. 30°00′.0 N. (assume nearest whole degree of latitude).

Declination 8°27′.5 S. (from Nautical Almanac).

Enter table with latitude 30°, declination 8°30′.0 contrary name to latitude, hour angle 43°, and take out the following:

Alt.	33°32′.3	$+\Delta d$ 71	*Az.* 126.0
Δd corr. for 2′.5	(+) 1′.8		*Zn.* 234.0
Hc	33°34′.1		
Ho	33°13′.7		
"a"	20′.4 away.		

The declination difference 2′.5 is the difference between the exact declination of 8°27′.5 and the tabulated declination 8°30′.0. The correction 1′.8 is obtained by multiplying 2.5 by 71, or obtained directly from the multiplication table. The correction is additive because the altitude is increasing as the declination decreases.

The hour angle is west so $Zn=360°-Z$. *Hc* is greater than *Ho*, therefore, "a" or altitude intercept is marked away from azimuth 234°.

This sight must be plotted from lat. 30°00′ N., long. 61°36′ W.

The apparent difference between the value of "*a*" as obtained from H. O. 211 will be recognized when it is recalled that the line of position as plotted will be 7.8 miles from lat. 30°14′.5 N., long. 61°30′.0 W. and at the same time 20.4 miles from lat. 30°00′.0 N., long. 61°36′.0 W.

PROBLEMS

17. Find the altitude intercept and azimuth of the following sights by H. O. 211 and H. O. 214. All altitudes are bubble octant.

(*a*) Sun. February 25, 1939, in lat. 30°04′.5 N., long. 81°10′.7 W., G. C. T. $15^h23^m18^s$, *Hs* 39°02′.0, I. C. (−) 1′.0.

(*b*) Sun. February 26, 1939, in lat. 30°15′.0 N., long. 93°41′.0 W., G. C. T. $21^h37^m43^s$, *Hs* 30°12′.0, I. C. (+) 1′.0.

(*c*) Sun. February 27, 1939, in lat. 30°08′.0 N., long. 121°17′.5 W., G. C. T. $18^h10^m33^s$, *Hs* 40°40′.0, I. C. 0′.

(*d*) Moon. June 12, 1939, in lat. 30°04′.0 N., long. 80°10′.0 W., G. C. T. $11^h55^m32^s$, *Hs* 63°06′.0, I. C. 0′

(*e*) Jupiter. February 15, 1939, in lat. 29°50′.0 N., long. 165°41′.0 W., G. C. T. $03^h59^m30^s$, *Hs* 23°50′.0, I. C. (+) 1′.3.

(*f*) Altair. October 5, 1939, in lat. 30°12′.3 N., long. 121°01′.0 W., G. C. T. $01^h32^m09^s$, *Hs* 60°05′.0, I. C. 0′.

(*g*) Altair. October 9, 1939, in lat. 29°48′.3 N., long. 82°12′.0 W., G. C. T. $05^h03^m10^s$, *Hs* 18°40′.0, I. C. (+) 1′.0.

(*h*) Enif. October 16, 1939, in lat. 29°53′.4 N., long. 122°18′.5 W., G. C. T. $07^h15^m12^s$, *Hs* 43°30′.0, I. C. (−) 1′.5.

(*i*) Enif. October 5, 1939, in lat. 30°19′.0 N., long. 39°56′.0 W., G. C. T. $03^h30^m15^s$ *Hs*. 30°40′.0, I. C. (+) 2′.0.

(*j*) Sun. February 28, 1939, in lat. 29°58′.0 N., long. 119°53′.6 W., G. C. T. $22^h50^m07^s$, *Hs* 36°17′.0, I. C. (+) 1′.2.

PLOTTING LINES OF POSITION

Ninety degrees minus the computed altitude of a star is the distance from the assumed position to the geographic position of a star. Ninety degrees minus observed altitude is the distance from the geographic position of the star to the position circle through the true position of the observer. Then the difference between the computed and measured altitude is the angular distance along the azimuth from the circle of position through the assumed position to the observer's circle of position. The angular distance is converted into miles using 1′ equals 1 mile. The difference between the two altitudes expressed in miles is known as the altitude intercept and is denoted by "*a*." When the observed altitude is greater, the observer's circle of position is obviously nearer the geographic position of the star than the assumed position.

To plot a line of position.—Plot the assumed or dead-reckoning position *used in solving the sight* on the chart. Through this point draw a dotted line in the direction of the body's azimuth with a small arrow on the end that points to the body. On this dotted line measure from the assumed position a distance equal to the altitude intercept, toward the body when the observed altitude is greater, away from the body when the computed altitude is greater. Through the point thus determined draw a line perpendicular to the azimuth line. This line will represent a portion of the circle of position and is re-

ferred to as a line of position. Since the circle of position in most cases is so large, a small portion of the arc is assumed to be a straight line without material error and is obviously perpendicular to the azimuth.

After the line of position is plotted, it should be labeled with the name of the body observed and the time of the observation.

A fix is an accurate determination of latitude and longitude. A line of position is not a fix, but is the locus of all possible positions of the aircraft at the time of the observation. If two lines of position for the same instant are determined their intersection is a "fix," for when an aircraft is on two lines at the same instant, it can only be at their intersection.

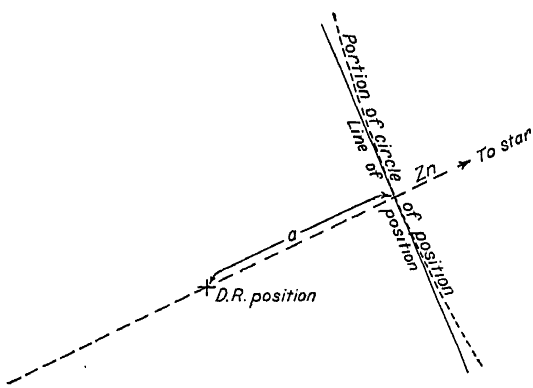

FIGURE 83.—Line of position.

Sights or observations are seldom taken exactly simultaneously. Usually the navigator wishes to take all of his own sights. This means that the times of each obervation will vary. This variation may be from 1 to 15 minutes, depending upon the state of the weather and the degree of cloudiness. Since the times of the observations vary, the times of the resulting lines of position will vary, and before a fix can be obtained the lines of position must be brought to a common time. To accomplish this the lines of position may be advanced or retarded along the course at the speed of the aircraft.

A line of position may be advanced as follows: In figure 85 let A be the dead-reckoning position at 1000 and SL a line of position obtained by an observation of the sun at that time. Let B be the dead-reckoning position at 1100. Then SL may be moved forward parallel to itself for the run of 1 hour. Thus by making $A'B'$ equal to AB, the position line may be drawn through B' parallel to SL as at $S'L'$. Then if SL was the locus of the aircraft's position at

1000, $S'L'$ will be the locus at 1100, provided SL has been moved to $S'L'$ for the course and ground speed. Suppose at 1100 the line of position CD is obtained by observation of another body. Then the intersection of CD with $S'L'$ is a running fix. Such a fix is not as dependable as simultaneous observations, as the accuracy is dependent upon the amount of change in wind conditions between the two observations. The position line may also be advanced by plotting the line of position from B using the data obtained by working the sight from A.

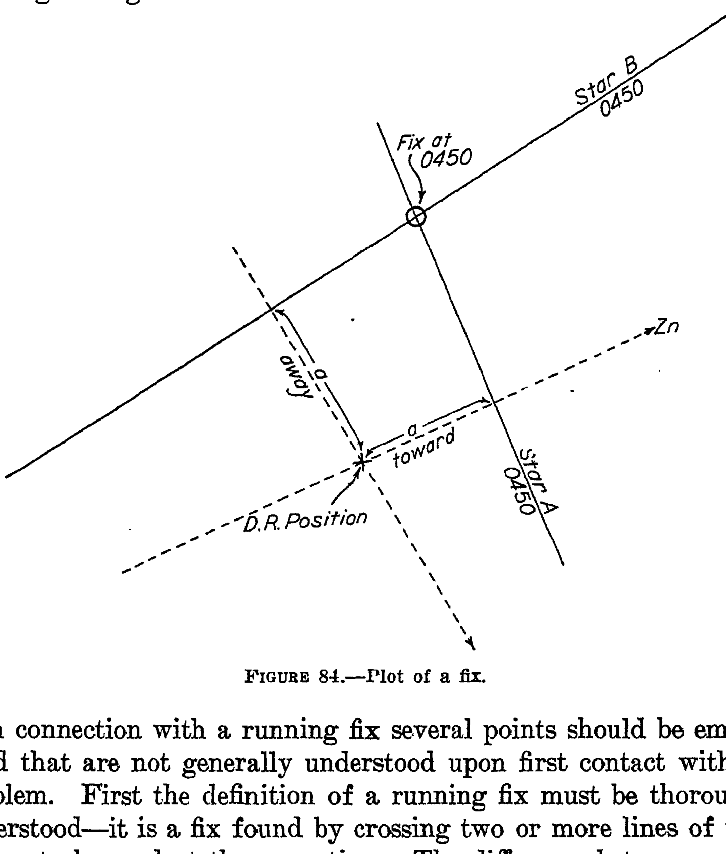

FIGURE 84.—Plot of a fix.

In connection with a running fix several points should be emphasized that are not generally understood upon first contact with the problem. First the definition of a running fix must be thoroughly understood—it is a fix found by crossing two or more lines of position not observed at the same time. The difference between a running fix and an ordinary fix is that in the latter the observations are taken simultaneously or so close together that the time between sights is negligible, in which case the lines may be plotted as observed and the fix taken as their intersection. But if two sights are not taken simultaneously, they cannot be crossed for a running fix until one has been moved either up to or back to the time of the other sight. The distance that the line is moved is, of course, the distance the aircraft moves during the interval between the two sights.

Before lines of position can be advanced and crossed correctly, it is necessary to have a clear and definite understanding of the results of a solution of an observation. All navigation observations are based on the same general principles—first the navigator assumes his position from the best information available; then, using this assumed position he finds what his observed altitude should be by a solution of the astronomical triangle; then, by a comparison of his computed altitude and his observed altitude, he finds the amount of error in the position he first assumed. The error is the "altitude intercept." The amount of this error is not important. It may be small or large depending on the accuracy of the assumed position. But regardless of the amount of error in the position used in solving the sight, the solution of the sight corrects for that error, by telling the navigator to plot his line of position so much nearer or so much farther away from the assumed and erroneous position. Thus it is seen that it is not absolutely necessary that the most accurate position be assumed for each and every sight. Therefore, two or three sights not taken simultaneously could be computed using a common assumed position. This would result in a different amount of error being introduced in the assumed position of each sight, but the solution of the sight itself would correct that error.

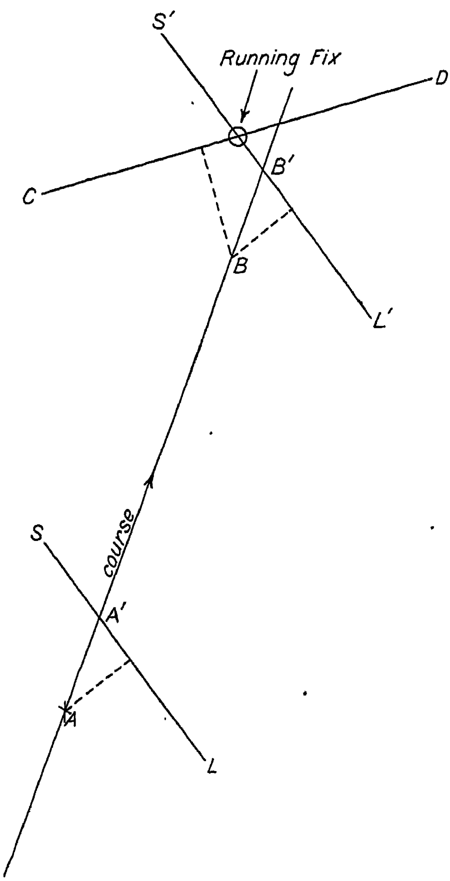

FIGURE 85.—Advancing a line of position.

Still another point to remember is that the solution of any sight gives the position at the time of that sight. Now if three lines are computed using the same assumed position, and each sight plotted from that assumed position, there would be three lines of position for three different times—the times of the three sights. The fact that

all three were plotted from a common assumed position does not mean that they are thus brought to a common time. The lines must still be advanced or retarded to a common time, in order to make a fix.

For example, with three sights at 0445, 0505, and 0515, speed 120 knots, all sights having been solved and plotted from a common assumed position. To cross for a fix at 0515, the 0445 line must be advanced along the course the distance the aircraft has moved in 30 minutes or 60 miles; the 0505 line must be advanced along the course the distance the aircraft has moved in 10 minutes or 20 miles. Since all lines have been advanced to 0515 they may be crossed for a fix.

It must not be assumed that three lines of position will invariably cross in a point. Usually the lines will form a small triangle of error and in this case, the fix is assumed to be about the center of the triangle.

PROBLEMS

18. October 20, 1939, a plane was in lat. 31°04'.0 N., long. 91°49'.0 W. G. C. T. $02^h00^m00^s$, course 170° T., ground speed 90 knots. About 30 minutes later two stars were observed with a bubble octant, I. C. 0'.0, as follows:

Star	*G. C. T.*	*Hs*
Enif	$02^h30^m15^s$	67°50'.0
Altair	$02^h35^m15^s$	48°43'.0

Required (1) fix at time of observation of Altair.

19. October 19, 1939, a plane was in lat. 28°50'.0 N., long. 121°20'.0 W., at G. C. T. $02^h15^m00^s$ on course 340° T., ground speed 120 knots. About 1 hour later 2 stars were observed with a bubble octant, I. C. (—) 1'.0, as follows:

Star	*G. C. T.*	*Hs*
Enif	$03^h15^m10^s$	67°14'.0
Altair	$03^h20^m11^s$	62°48'.0

Required (1) fix at time of observation of Altair.

LATITUDE BY POLARIS

Using the star, Polaris, an observer may determine his latitude with a small amount of computation. The latitude is similar to a line of position parallel to the equator. If Polaris were located directly at the North Pole, the true altitude of Polaris would be the observer's latitude. However, it is not exactly over the pole but moves around it in a small circle with a radius of about 1°2'.5. When Polaris is directly above the pole this radius must be subtracted from the altitude to find the latitude, and when directly below the pole it must be added. When the star is directly east or west there is no correction. The correction varies with the L. H. A.

In the Nautical Almanac special tables are set aside for the star, Polaris. From this section the G. H. A. for 0 hours for any day may

be found. As with any other star this tabulated value is corrected by using the table "Correction to be added to the tabulated Greenwich hour angle of stars." The local hour angle, either east or west, is found by combining the longitude with the Greenwich hour angle. After the L. H. A. is found, enter table III of the Nautical Almanac with the L. H. A. and obtain the correction to be applied to the true altitude to obtain the latitude. The correction is applied as indicated by the sign. Latitude as determined by Polaris is always north as Polaris is only visible north of the equator. In table IV with the arguments L. H. A. and Lat. the azimuth may be found by inspection.

Example.—January 1, 1939, in long. 72°30′.0 W. Find the latitude by Polaris. *Hs* 32°52′.5 (octant); I. C. (−) 2′.5; G. C. T. $06^h15^m20^s$.

G. H. A. 0^h January 1, 1939,	74°01′.4	I. C.	(−) 2′.5
corr. 6^h15^m	94°00′.4	Table E	(−) 1′.5
corr. 20^s	5′.0		———
	———	corr.	(−) 4′.0
G. H. A.	168°06′.8	*Hs*	32°52′.5
Long.	72°30′.0 W.		———
	———	*Ho*	32°48′.5
L. H. A.	95°36′.8 W.	*Azimuth (table IV)*	
Ho	32°48′.5	N. 1°.2 W.	
corr. from table III (+)	6′.6		
Lat.	32°55′.1 N.		

PROBLEMS

20. Find the latitude by Polaris.

(*a*) January 22, 1939, in long. 18°31′.0 W., G. C. T. $05^h10^m05^s$, *Hs* 53°18′.0, I. C. (+) 1′.0.

(*b*) April 10, 1939, in long. 39°28′.0 W., G. C. T. $07^h12^m18^s$; *Hs* 27°18′.5, I. C. (−) 1′.0.

(*c*) June 14, 1939, in long. 141°15′.8 W., G. C. T. $07^h56^m32^s$, *Hs* 20°55′.0, I. C. (+) 2′.0.

(*d*) August 3, 1939, in long. 91°55′.0 W., G. C. T. $06^h48^m53^s$, *Hs* 35°05′.0, I. C. (−) 2′.0.

(*e*) November 1, 1939, in long. 60°10′.0 E., G. C. T. $04^h10^m08^s$, *Hs* 41°10′.0, I. C. (+) 1′.8.

21. October 18, 1939. A plane was in lat. 31°35′.0 N., long. 92°50′.0 W., at G. C. T. $00^h15^m00^s$ course 240° T., ground speed 180 knots. About 1 hour later three stars were observed with a bubble octant I. C. 0′.0, as follows:

Star	*G. C. T.*	*Hs*
Altair	$01^h05^m25^s$	66°38′.0
Polaris	$01^h10^m27^s$	30°26′.0
Enif	$01^h15^m26^s$	64°12′.0

Required (1) fix at the time of the observation of star Enif. See figure 86.

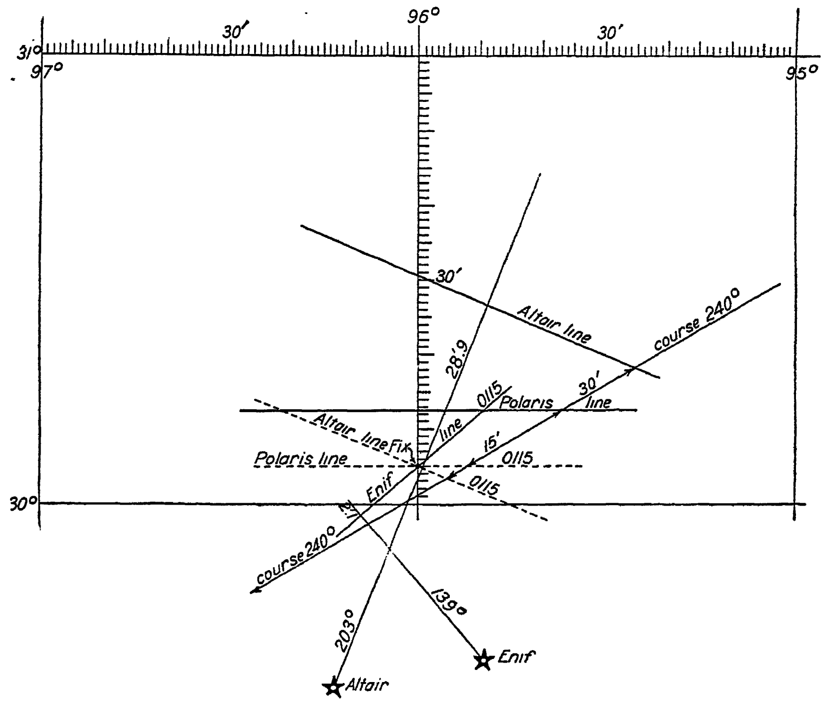

FIGURE 86.

Example 21 solved by H. O. 214

Co.	Dist.	D. L.	Dep.	D. long.	D. E.				
240°	180	90'	156	182'		Lat.	31°35' N.	Long.	92°50' W.
						D. L.	1°30' S.	D. long.	3°02' W.
						Lat. in	30°05' N.	Long. in	95°52' W.

ALTAIR

Dec.	+8°42'.8		
G. C. T.	1h05m25s		
Oct. 18, G. H. A. 0h	88°37'.3		
Corr. 1h05m	16°17'.7		
Corr. 25s	6'.3		
G. H. A	105°01'.3 W.		
Long.	96°01'.3 W.		
L. H. A.	9°00'.0 W.		
	Alt.	*d*	*Z*
	66°54'.5	+93	156°.8
Corr. 12'.8	+11'.9		
Hc	67°06'.4		
ho	66°37'.5		
	28'.9 away from 203°		
H8	63°38'.0		
Corr.	−.5		
Ho	66°37'.5		

ENIF

Dec.	+9°36'.2		
G. C. T.	1h15m26s		
Oct. 18. G. H. A. 0h	60°16'.4		
Corr. 1h15m	18°48'.1		
Corr. 26s	6'.5		
G. H. A.	79°11'.0 W.		
Long.	96°11'.0 W.		
L. H. A.	17°00'.0 E.		
	AH	*d*	*Z*
	64°04'.4	+81	138°.8
Corr. 6'.2	+5'.1		
hc	64°09'.5		
ho	64°11'.5		
	2'.0 towards 139°		
Hs	64°12'.0		
Corr.	−.5		
Ho	64°11'.5		

POLARIS

G. C. T.	1h10m27s
Oct. 18, G. H. A. 0h	359°32'.6
Corr. 1h10m	17°32'.9
Corr. 27s	6'.8
G. H. A.	377°12'.3 W.
Long.	95°52'.0 W.
L. H. A.	281°20'.3 W.
hs	30°26'.0
Corr.	−1'.7
ho	30°24'.3
Corr.	−11'.5
Lat.	30°12'.8 N.
Az.	1° 2'

STAR IDENTIFICATION

Before an observation of a star can be solved the name of the star must be known. One way of learning the stars is to study a map of

the heavens and learn the names and positions of the various constellations and the positions of the bright navigational stars in each. This is generally a long process as the entire picture of the heavens will change in the course of a year. The Hydrographic Office star finder has become the best recognized method for easily identifying stars. The finder consists essentially of a rotatable disk on which the positions of the navigational stars are indicated. By rotating the star disk until the local civil time is opposite the date on the outside circle and then superimposing the proper latitude grid sheet on the meridian line, a star can be identified knowing its altitude and bearing. This star finder has also the correction for an observation of Polaris marked opposite the local civil time. This correction can be applied instead of table I in the Nautical Almanac.

Each tabular method used for solving the astronomical triangle has an explanation of how a star may be identified from its observed altitude and bearing.

HOUR ANGLE FROM SIDEREAL TIME

The G. H. A. for 54 stars is tabulated in the almanac. In addition the right ascension and declination of 110 additional stars are tabulated. The local hour angle of the additional stars may be found

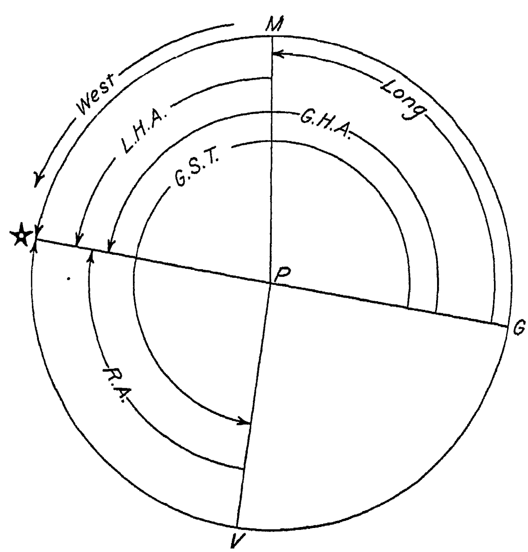

FIGURE 87.—Hour angle from sidereal time.

from a knowledge of sidereal time and right ascension. If a watch rated to sidereal time is not available, sidereal time may be found from the Nautical Almanac. The first table in the almanac headed sidereal time of 0^h G. C. T. contains the value of sidereal time for

0 hours of every day. At the bottom of the same page is a correction table that may be used for converting civil time into sidereal time. If the value of sidereal time for 0 hours, the time of the observation, and the correction are *added* together, the sum is the Greenwich sidereal time at the instant of observation. This is the hour angle of the vernal equinox from the meridian of Greenwich (fig. 87). The right ascension of the star is measured to the eastward from the vernal equinox. The Greenwich hour angle can then be found by combining the two. Since sidereal time and right ascension are in units of time, the G. H. A. will be in time units. It may be converted into arc by means of table VIII of the Nautical Almanac. Now combine the longitude with the G. H. A. for the L. H. A. The following example illustrates the method:

Example.—January 1, 1939, in longitude 80°31′.5 W., G. C. T. $09^h22^m30^s$. Find the local hour angle of the star B Canis Majoris.

G. S. T. 0^h January 1	$06^h38^m59^s.4$	G. C. T	$09^h22^m30^s$
Time of observation	$9^h22^m30^s.0$	Sidereal time 0^h	$6^h38^m59^s.4$
corr. for $9^h22^m30^s$	$1^m32^s.4$	Corr. G. C. T	$1^m32^s.4$
G. S. T.	$16^h03^m01^s.8$	G. S. T.	$16^h03^m01^s.8$
R. A. of star	$6^h20^m00^s.7$	R. A. of star	$6^h20^m00^s.7$
G. H. A.	$9^h43^m01^s.1$ (Time)	G. H. A.	$9^h43^m01^s.1$
or	145°45′.3 (Arc)	or	
Long.	80°31′.5	Arc	145°45′.3 W.
L. H. A.	65°13′.8 W.		

Table VIII

9^h40^m	145°
3^m	45′
1.1^s	16″
	145°45′16″
	or 145°45′.3

PROBLEMS

22. With the sidereal time and right ascension of the following stars, find the local hour angle:

(*a*) Almach, April 14, 1939, in long. 55°01′.0 E., G. C. T. $04^h30^m10^s$.
(*b*) El Nath, January 20, 1939, in long. 76°18′.0 W., G. C. T. $06^h17^m23^s$.
(*c*) Phact, May 27, 1939, in long. 9°48′.7 W., G. C. T. $10^h09^m42^s$.
(*d*) Merak, February 14, 1939, in long. 121°13′.5 W., G. C. T. $11^h16^m04^s$.
(*e*) Alcyone, March 5, 1939, in long. 123°41′.0 W., G. C. T. $03^h27^m52^s$.

STAR ALTITUDE CURVES

An observer's position on the earth's surface is definitely determined by the simultaneous altitudes of two stars and the correct Greenwich

civil time of the observations. This may be put in graphical form by plotting the altitudes against latitude and sidereal time. From these equal altitude curves the intersection of the simultaneous altitudes of two stars gives the latitude and local sidereal time of the observer. The local sidereal time, when combined with the Greenwich sidereal time of the observations, gives the longitude of the observer. Both latitude and longitude are determined without any reference to a dead-reckoning position, right ascension, hour angle, azimuth, or declination. There is no plotting and the only computation is in combining the local sidereal time and Greenwich sidereal time and converting to arc.

The present altitude curves are made for three stars so chosen that their altitude lines will give a clear-cut intersection. When possible, Polaris and some star bearing approximately due east or due west is used. The third star is chosen so that its curve will make an angle of from 20° to 70° with that of Polaris.

The curves as constructed include the correction for parallax, so that, with an altitude measured by a bubble octant, it is only necessary to correct for the instrument error.

By using a watch set to Greenwich sidereal time the following steps are necessary to obtain a fix with the curves:

(*a*) Measure the octant altitudes and note the Greenwich sidereal time.

(*b*) Adjust for the run between observations. This may be done directly on the curves.

(*c*) Find the intersection of the altitude curves, and read the corresponding latitude and local sidereal time.

(*d*) Find the difference between the local sidereal time and Greenwich sidereal time; this time converted to arc gives the longitude.

The disadvantages of the star altitude curves are:

(1) The "fixed" stars are not absolutely fixed and new curves must be computed and printed at intervals.

(2) It may not be possible to observe the particular stars for which the curves are constructed, in which case observations would have to be made and worked by the use of tables and the Nautical Almanac.

Star altitude curves have been computed and are available through the "Weems System of Navigation," Annapolis, Md.

PRECOMPUTED ALTITUDE CURVES

It is impracticable to compute and plot as curves the altitudes of the sun, moon, and planets because the rapid change in right ascension and declination would cause them to be out of date within an hour. It is possible, however, to precompute altitudes for use during a particular flight.

In preparing for a flight it is possible to lay down the course and predicted ground speed. If the time of departure is known the probable position of the aircraft for any instant can be determined. By using a series of such positions, at reasonable intervals of time, it is possible to compute a series of altitudes for any celestial body. The altitudes may then be plotted against time and a smooth curve drawn.

In flight, it is then only necessary to observe the altitude and compare it with the precomputed altitude for that time. If the observed altitude is the same as the computed altitude, the aircraft is at the estimated position or on a line of position passing through it. If the two altitudes are different, the aircraft is either ahead or behind of a line of position through the estimated position.

The use of precomputed curves makes it possible for a ground staff to do most of the computations before the aircraft departs. The advantages of this are obvious.

If the course and time—table for which the altitudes were computed are not followed, the curves are still of value. The curves are not only designed to show if an aircraft is on schedule, but also if it is off, and, if so, by how much. If the prearranged course and speed were always followed, no other method would be required to supplement the dead reckoning.

MECHANICAL SOLUTIONS

In addition to nautical tables for solving the astronomical triangle there are available several mechanical devices. Some of these are in the form of slide rules, others are curves, and some have arms representing the three sides of the triangle. Among some of the later instrumental developments are the "Hagner position finder" and "Maxon line of position computer."

THE AIRCRAFT OCTANT

The aircraft octant Mk. III—Mod. 4, as shown in figure 88, provides means for measuring the angular altitude of a celestial body by reference both to the natural horizon and to a bubble artificial horizon, vision of the celestial body being by reflection through a totally reflecting prism.

The instrument consists essentially of a rotatable prism (9) rigidly connected to a worm gear meshing with a worm operated by knob (1). The latter's periphery is divided into 10 major parts, each reading 1°, and subdivided into 12 parts, each reading 5′ of arc.

The limb of the arc is visible through the window (2) and carries a graduation line for each 10°. When reading the instrument, the

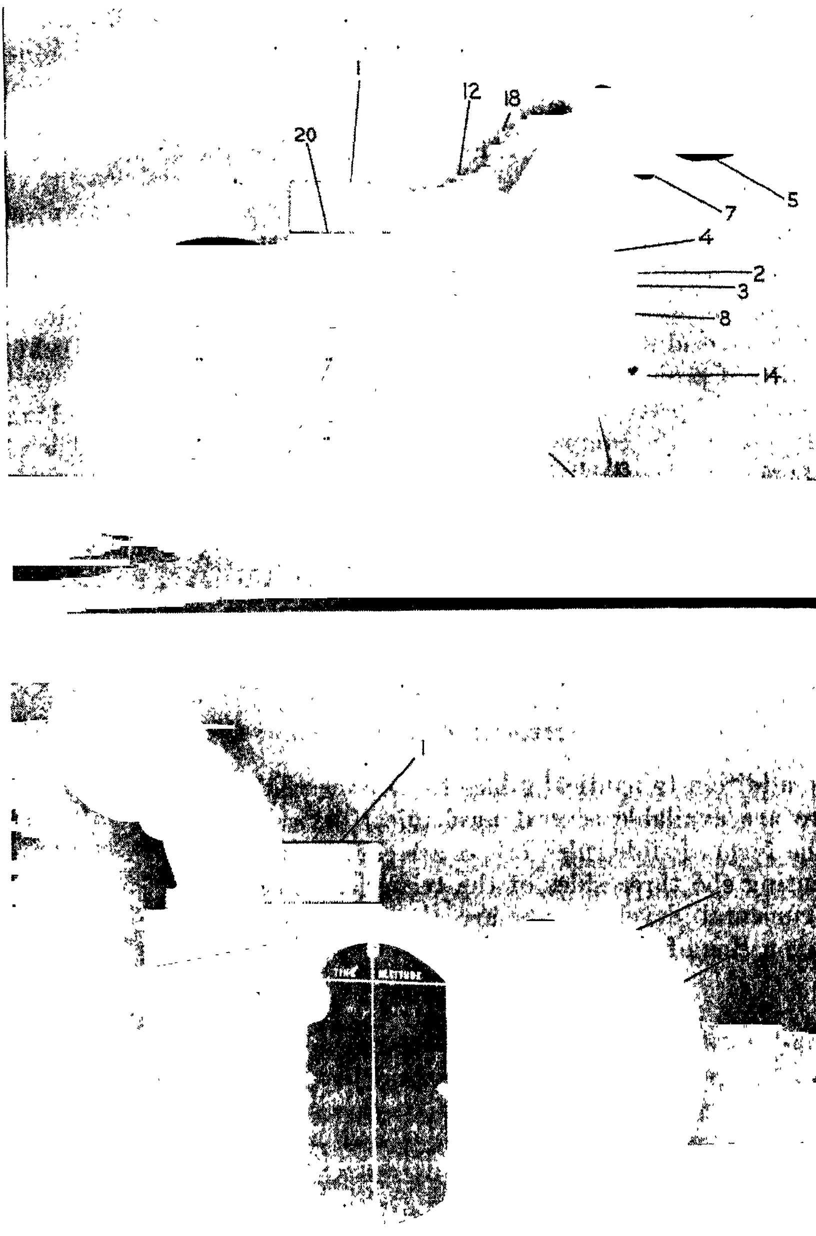

FIGURE 88.—Aircraft octant.

tens of degrees are taken through the window, while the units degrees and minutes are read directly from the micrometer drum.

The telescope system consists of an objective lens, a total reflection prism encased in the body, a bubble chamber assembly (4) including means for illuminating the bubble, and the eyepiece (5). The stationary prism (3) is used when taking sights on the sea horizon.

Artificial horizon.—The bubble chamber and the diaphragm chamber being component parts of single piece of metal are extremely rigid and substantial. The bubble chamber, with glass top and bottom, forms a part of the optical system of the telescope. The two chambers, with a small connecting passageway, are completely filled with a transparent liquid. The knob (8) controls the position of the diaphragm, and thereby forms a bubble or controls its size.

For night observation two methods of illumination of the bubble are provided. Radium luminous material, painted on surfaces surrounding the transparent ring furnishes light for illumination of the bubble. For still brighter intensity electric illumination is provided. Immediately below the glass bottom of the bubble chamber is placed a ring of transparent material that reflects light gathered from the small electric light (2) upward. Inside the bubble chamber a reflector is so placed that the light from the ring is reflected uniformly, illuminating the bubble from the sides. The intensity of the light from the lamp may be controlled by rotating the disk (3) containing various size openings.

Eye-piece.—The eye-piece proper, consisting of a 45° prism and eye lens, has been made rotatable around the vertical axis to permit observation to the rearward without compelling the observer to assume strained positions when sitting in a narrow cockpit.

The eye buffer and eye lens are rotatable. The eye lens is adjusted for focus by rotation of the nut (7).

The telescope objective lens is equipped with a shutter operated by means of a knob (10) the function of this shutter being that of preventing vision through the fixed prism when using the artificial horizon and, when out of the way, permitting vision through the same prism when the natural horizon is being observed.

A rotatable disk (11) carries a number of colored filters to be used when observing the sun, and a blank hole to be used when observing stars, the moon or terrestrial objects.

The astigmatizer is operated by the small knob (12). The function of the astigmatizer is that of elongating the image of the sun or moon to a band of light about 3° long, and the image of a star to a line of light of the same length. This renders the observations more accurate in certain cases, by enabling the observer to bisect the bubble with the line formed by the astigmatizer, rather than bringing the true image of a star or of the sun to the same horizontal level as the bubble by placing the two objects side by side.

Optical layout.—Figure 89 gives a layout of the optics of the instrument. The purpose of each part is as follows:

1. The horizon and index prisms are both reflecting prisms. The direction of the rays of light which pass through the prism and through the objective, is determined by the position of the prisms. Lines *ABCDE* and *A′B′C′D′E′* show paths of rays of light through the prisms for two different positions.

2. The objective lens causes the rays of light passing through it to come to a focus and form an image of the observed body at the bottom surface of the field lens.

3. The function of the astigmatizer lens has been explained above. Whenever the lens is thrown out of the optical path a parallel plate glass is substituted to compensate for a change in focal length.

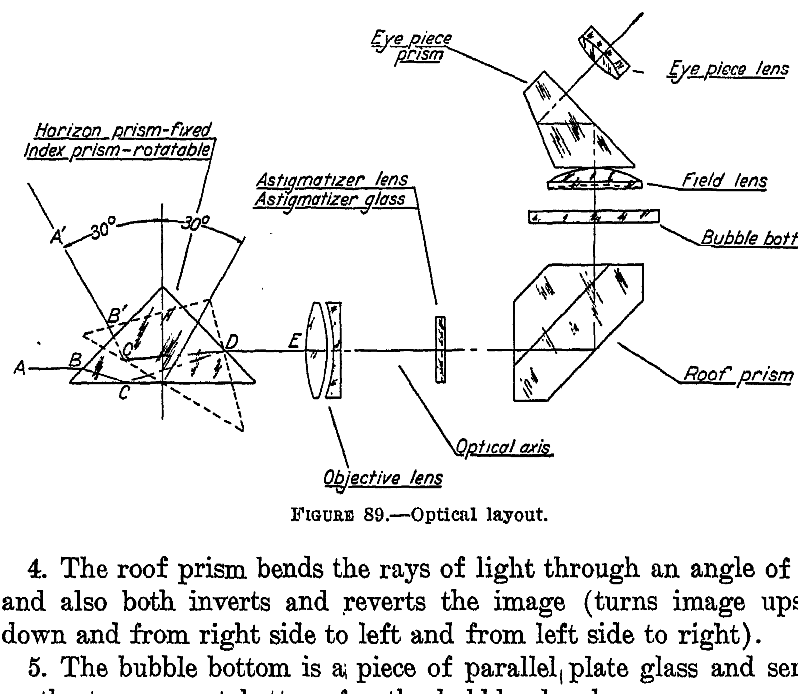

FIGURE 89.—Optical layout.

4. The roof prism bends the rays of light through an angle of 90° and also both inverts and reverts the image (turns image upside down and from right side to left and from left side to right).

5. The bubble bottom is a piece of parallel plate glass and serves as the transparent bottom for the bubble chamber.

6. The field lens forms the top of the bubble chamber, its under surface having such a curvature that the rate of motion of the bubble, when the octant is tilted, is the same as that of the image of the celestial body. It also acts as a lens in the optical system.

7. The eye-piece prism bends the rays through an angle of 45°.

8. The eye-piece is adjustable in position for focusing the image and the bubble. It is of such a power that together with the other lenses of the system it gives a magnification of two diameters.

Operating instructions.—The instrument should be held in both hands, the arms resting easily on the sides of the chest, as shown in figure 90. The right hand operates the micrometer worm, while the left, beside furnishing additional support, operates the colored filters and the astigmatizer.

When the artificial horizon is used, the knob (10, fig. 88) should be moved to its extreme position in the direction opposite to the arrow. This will exclude any direct horizontal light from entering the telescope.

To form the bubble, hold the instrument on its side with the bubble diaphragm at the bottom, and turn the knurled knob (8, fig. 88) clockwise (as for winding a watch) slowly. The appearance of the bubble is ordinarily announced by a sharp click. The instrument

FIGURE 90.—Position of octant in use.

should then be uprighted and the bubble should be seen, looking through the telescope eyepiece. If the bubble is not visible, relieve the tension on the diaphragm by turning the nut counterclockwise and turn the octant again on its side as explained before to allow the bubble to pass from the diaphragm chamber to the bubble chamber, the two being connected by a passageway.

Ordinarily, the click is heard and the bubble appears immediately, but should the diaphragm fail to click, and should the bubble fail to appear in the telescope, this means that the bubble is already formed inside the diaphragm chamber and must be compressed to a smaller size in order to allow it to flow through the tube connecting the diaphragm chamber to the level chamber. This is done by turning knurled nut counterclockwise until resistance is felt. Do not forget to bring the octant on its side to let the bubble run through.

Once the bubble has appeared, its size can be varied by turning the knob either way, to compress or expand it.

The instrument optics are so designed that the matching of the image of the bubble with that of the sun or star must not necessarily take place in the middle of the field. This matching, which we call collimation, is shown in figure 91 (*a*), approximately in the center of the field. The image of the sun is brought alongside of the bubble so that the center of the sun and that of the bubble are on the same horizontal line. It does not matter if the two images are collimated in the position shown in (*c*) or (*d*). If the two are collimated, as shown in (*e*), the error resulting therefrom will be of the order of 5 minutes, while the example shown in (*f*) also gives an error.

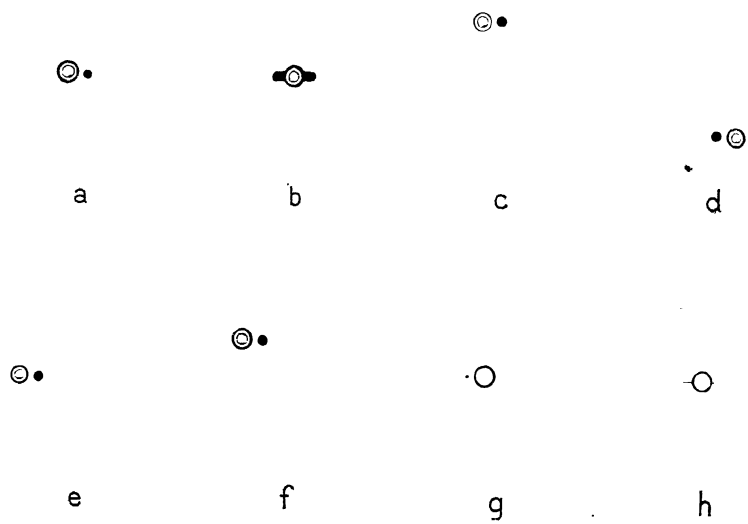

FIGURE 91.—Collimation.

(*b*) shows collimation when the image of the sun is astigmatized. This method is preferred by many and it is, in fact, preferable for accurate work because the symmetrical arrangement of the images makes it easier to estimate the center of the bubble.

(*g*) shows the same work done with a star, and (*h*) with the astigmatized image of a star.

Stars are not as plainly visible or identifiable when astigmatized and it is, consequently, the best procedure to bring them approximately in collimation before astigmatizing and then switch on the astigmatizer for final adjustment.

The size of the bubble which gives the best results is that a little over twice the apparent size of the sun as seen in the telescope, namely, approximately $\frac{1}{10}$ of the size of the field. This diameter is given by the distance, between the outer ends of the two short horizontal

lines etched on the field lens. This, however, is not a hard and fast rule. The smaller the bubble the more sluggish it will be, while a large bubble will tend to move faster. Depending on the conditions, the most suitable size of bubble is selected, trying to avoid too small a bubble.

The horizon and index prisms are so placed that the fields through these prisms are visible simultaneously when the eye is placed approximately at the center of the eye-piece lens. If the eye is moved to the right side, the index prism field is visible, to the left side, the horizon prism field comes into view. If the eye is moved from one side to the other there is a region in which both fields are visible.

For night work the light furnished by the radium luminous material is usually sufficient for illuminating the bubble. Should more illumination be necessary, electric illumination is provided. The switch (14, fig. 88) mounted on the back of the telescope controls the light. The disc (3, fig. 88) when rotated varies the intensity of illumination. Only sufficient intensity should be used as to make the bubble clearly visible.

The lamp for producing the illumination of the bubble is shown at (2, fig. 88). It is removable by unscrewing it from the base. A spare lamp will be found in the carrying case.

Stars are visible with enhanced brilliancy, undisturbed by the illumination of the bubble which appears as an illuminated ring in a dark field. By virtue of this method of illumination stars of second magnitude are easily and perfectly observable even under unfavorable conditions.

A lamp has been provided for illuminating the graduations, the record pad, and the watch. The lamp cap should be turned with the large slot toward the data pad.

The lamp holder will be found in a screw receptacle in the cover of the carrying case. It should be inserted in the threaded hole under the micrometer drum.

The battery (Bright Star No. 11 or equivalent) should be inserted into the holder under the telescope in the direction indicated on the clamp. It is not necessary to remove the paper jacket from the battery.

The contact button for the watch and the record pad lamp is located at the top of the left-hand handle.

After using the octant, turn the knurled knob in the direction of least resistance until it feels quite free. This is done to avoid useless strain on the diaphragm. Unless this is done the diaphragm will assume a set position and lose its elasticity to such an extent that the necessary range of control of the bubble cannot be had.

Pre-flight inspection.—See that the bubble can be properly formed, that the lights function and that the controls work properly.

In order to check the instrument for change in adjustment due to accidental damage or rough treatment sights should be taken on some distant object using both horizon and index prisms. If, for coincidence of the images, a reading of greater than plus or minus 2 minutes from the zero graduation is obtained one of the prisms has shifted in position and should be readjusted. It does not indicate which prism has shifted, but, since it is unlikely that both prisms will shift the same amount, it will indicate when an adjustment of the instrument should be made. The method of making the adjustment is covered by instructions issued by the company manufacturing the octant and it is not deemed necessary to repeat it here.

Accuracy in taking sights is directly proportional to the number of sights taken. Sights should be taken at every available opportunity. Long intervals between the taking of sights should be avoided as accuracy depends on continous practice. The beginner will usually have difficulty holding the bubble steady near the center of the field. The bubble will be in this position only when the octant is held perfectly level in both the fore-and-aft and athwartships position. When matching the celestial body with the bubble, remain in a relaxed position elbows braced against the chest, take a half breath and hold the breath for the final adjustment. If the celestial body is far to one side of the bubble, the star is not being faced squarely and the whole body will have to be turned to the right or left to get the star in contact with the bubble. If the celestial body is above or below the bubble, bring the star up or down to the bubble by moving the knurled altitude knob. Greatest accuracy is obtained if the sight can be taken in a few seconds. If too much time is spent at it, the observer becomes nervous and strained and the results inaccurate.

In aircraft it will be necessary to take a series of five or ten sights in as short a time as possible. The times and altitudes are then averaged, either arithmetically or graphically, and the averages used in the computations.

Probably a faster method than either the arithmetical or graphical average is the median method. In this method an odd number of sights is taken and the time of the first and last sights averaged. Beginning with the lowest octant reading, the lowest altitudes are thrown out until the middle reading is reached. This altitude and time are used in solving the sight.

Example.—

	Time		Altitude		Time		Altitude
1.	$10^h14^m00^s$	X2	24°45′.0	7.		→	26°15′.0
2.		X3	25°00′.0	8.			26°45′.0
3.		X5	26°10′.0	9.			27°00′.0
4.		X4	25°45′.0	10.			28°00′.0
5.			28°00′.0	11.	$10^h18^m00^s$		28°30′.0
6.		X1	24°00′.0				

Average time $10^h16^m00^s$ Altitude used 26°15′.0

Sights should be taken as rapidly as possible as inaccuracies enter when the sights are extended over too long a period of time. Three minutes or less should be the rule for a series of sights. Sights should be taken only when in level flight—never in a climb or when descending, as errors of acceleration will be introduced. There are usually short periods of calm in an aircraft when two or more good sights can be obtained. As a general rule take observations from a point as close to the center of gravity of the aircraft as possible to reduce any possible error of acceleration or whip to a minimum. The matching of the bubble and the celestial body should be made when the bubble is stationary either in the upper or lower part of the field and not on the fly or when the bubble passes the body. Care must be taken that the bubble is not touching the casing but is absolutely free.

WATCHES

The aircraft navigational watch, as shown in figure 92, affords a means of obtaining the exact Greenwich Civil Time. It is an accurate watch constructed to run approximately forty hours, stem wound, with an indicator dial to show the state of winding. The watch is carried in its carrying case which consists of a wooden box, fitted with a hinged top and having a glass window through which to read the watch without removing it from the case. A felt-lined wooden block with thermometer attached, supports the watch inside the case, and sponge rubber between the box and block holds the watch firmly in place when the hinged top is closed, and affords maximum protection against shocks, jars and vibration. The watch is stowed in a special recess in flight.

Watches are supplied adjusted to civil time or to sidereal time. Dials are appropriately and conspicuously marked Greenwich civil time or Greenwich sidereal time.

Watches are wound each day to the same degree of tightness and the watch is compared with the daily time tick received from the Naval Observatory. This daily comparison and the temperature reading is logged in a notebook called the watch log, and the daily difference and watch rate is thereby established. The watch should

never be reset but the error figured from the time tick and the daily rate. The rate will vary with the position of the watch so the watch should be kept in a horizontal position. Navigational watches should

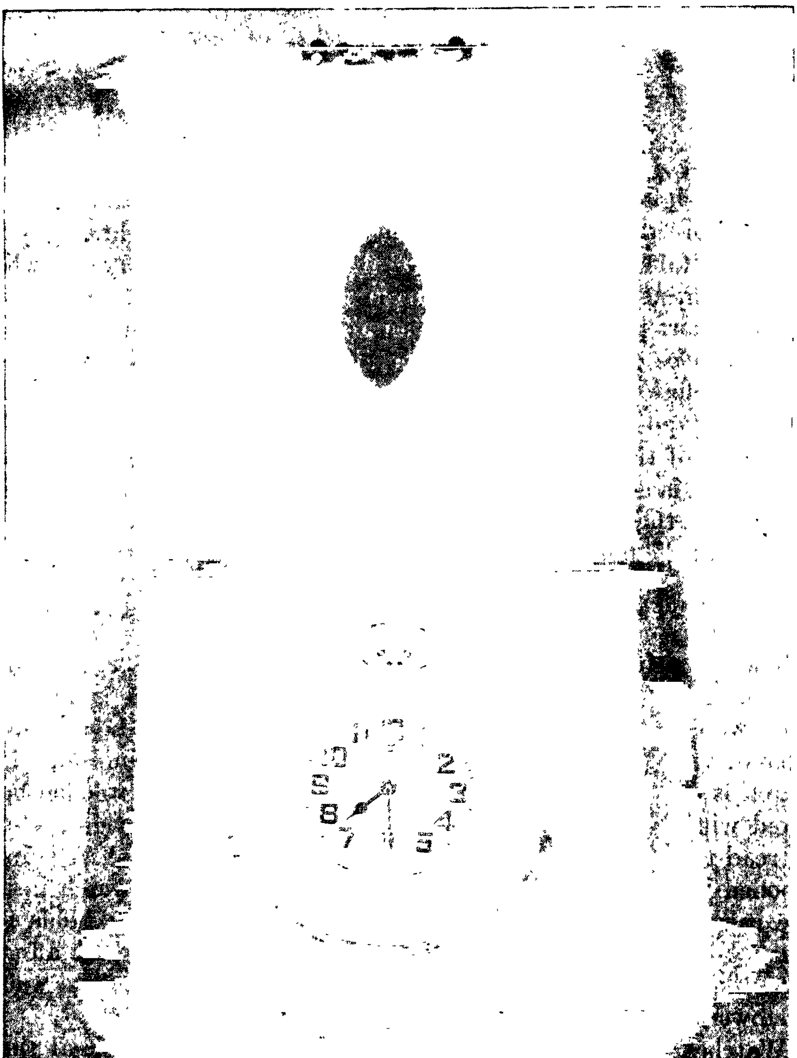

FIGURE 92.—Aircraft navigational watch and case

be handled carefully as they are delicate instruments and can be easily damaged and their accuracy and usefulness impaired.

In addition to the navigation watch a stop watch is generally carried. The stop watch may be set to the nearest minute by comparison

with the navigational watch and then the sweep second hand started at such a time to include the watch correction, thus reading G. C. T. or G. S. T. correctly. For example, if the navigational watch is 15 seconds fast on G. C. T. the stop watch would be started when the second hand of the navigational watch was 15 seconds past the minute. It would then read the exact Greenwich civil time. The stop watch is used in conjunction with the octant for taking sights, the sweep second hand being used for reading seconds of time. The stop watch is not stopped for each observation but is usually handled by an assistant who notes and records the time and altitude of each observation. The rate of the stop watch is not accurate and it should be set immediately prior to making observations. The error in the watch for this short interval is not large enough to be of any consequence.

ANSWERS TO PROBLEMS

1. (*a*) 74°34′.2 E.
   (*b*) 56°40′.9 W.
   (*c*) 37°08′.6 E.
   (*d*) 25°44′.4 E.
   (*e*) 40°32′.5 W.
2. (*a*) 36°25′.0 E.
   (*b*) 53°48′.9 W.
   (*c*) 23°58′.0 E.
   (*d*) 65°28′.0 W.
   (*e*) 91°17′.1 W.
3. (*a*) 40°21′.8 E.
   (*b*) 164°57′.2 E.
   (*c*) 83°48′.6 E.
   (*d*) 154°42′.8 E.
   (*e*) 154°45′.9 E.
4. (*a*) 137°18′.1 W.
   (*b*) 62°11′.0 W.
   (*c*) 49°56′.1 W.
   (*d*) 47°36′.2 W.
   (*e*) 91°13′.8 E.
5. (*a*) 8°10′.2 S.
   (*b*) 9°27′.9 S.
   (*c*) 8°33′.4 S.
   (*d*) 8°51′.3 S.
   (*e*) 8°40′.1 S.
6. (*a*) 8°25′.6 N.
   (*b*) 1°56′.7 N.
   (*c*) 11°52′.1 N.
   (*d*) 5°41′.8 N.
   (*e*) 0°57′.2 S.
7. (*a*) 6°51′.9 S.
   (*b*) 7°25′.8 S.
   (*c*) 10°51′.3 S.
   (*d*) 5°17′.7 S.
   (*e*) 8°44′.7 S.
8. (*a*) 38°44′.0 N.
   (*b*) 56°55′.8 S.
   (*c*) 29°56′.4 S.
   (*d*) 14°53′.1 N.
   (*e*) 26°22′.3 S.
9. (*a*) 70°39′.3
   (*b*) 37°37′.5
   (*c*) 52°49′.4
10. (*a*) 31°25′.3
    (*b*) 28°33′.6
    (*c*) 43°26′.3
11. (*a*) 23°00′.0
    (*b*) 55°57′.6
    (*c*) 73°48′.8
12. (*a*) 32°10′.5
    (*b*) 65°48′.9
    (*c*) 46°46′.7
13. (*a*) 67°11′.8
    (*b*) 32°23′.6
    (*c*) 47°47′.5
14. (*a*) 59°44′.7
    (*b*) 26°23′.7
    (*c*) 41°28′.3
15. (*a*) 33°31′.5
    (*b*) 66°06′.0
    (*c*) 84°43′.5
16. (*a*) 38°14′.6
    (*b*) 71°54′.6
    (*c*) 53°28′.1
17. (*a*) H. O. 211 "a" 3.5 miles away, *Zn* 135°11′.5.
    H. O. 214 Lat. 30°00′.0 N., long. 81°30′.2 W. "a" 5.3 miles toward, *Zn* 135.0°
    (*b*) H. O. 211 "a" 11.9 miles toward, *Zn* 237°14′.5
    H. O. 214 Lat. 30°00′.0 N., long. 94°09′.5 W. "a" 17.3 miles away, *Zn* 237.2°
    (*c*) H. O. 211 "a" 4.6 miles away, *Zn* 136°25′.5
    H. O. 214 Lat. 30°00′.0 N., long. 121°24′.3 W. "a" 5.9 miles away *Zn* 136.2°
    (*d*) H. O. 211 "a" 1.3 miles toward *Zn* 141°48.0
    H. O. 214 Lat. 30°00′.0 N., long. 79°58′.5 W. "a" 8.0 miles away, *Zn* 141.9°
    (*e*) H. O. 211 "a" 3.5 miles toward, *Zn* 243°51′.5
    H. O. 214 Lat. 30°00′.0 N., long. 165°52′.7 W. "a" 1.4 miles away, *Zn* 243.7°

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(*f*) H. O. 211 "a" 7.1 miles away, *Zn* 131°33′.0.
H. O. 214 Lat. 30°00′.0 N., long. 120°54′.5 W. "a" 19.2 miles away, *Zn* 131.8°

(*g*) H. O. 211 "a" 5.1 miles toward, *Zn* 269°27′.0
H. O. 214 Lat. 30°00′.0 N., long. 81°44′.9 W. "a" 28.4 miles toward, *Zn* 269.5°

(*h*) H. O. 211 "a" 6.0 miles toward, *Zn* 253°50′.0
H. O. 214 Lat. 30°00′.0 N., long. 122°24′.0 W. "a" 2.9 miles toward, *Zn* 253.5°

(*i*) H. O. 211 "a" 13.3 miles toward, *Zn* 263°09′.0
H. O. 214 Lat. 30°00′.0 N., long. 40°09′.9 W. "a" 0.9 mile away, *Zn* 263.1°

(*j*) H. O. 211 "a" 3.5 miles away, *Zn* 231°22′.5
H. O. 214 Lat. 30°00′.0 N., long. 120°21′.0 W. "a" 20.8 miles away, *Zn* 231.0°

18. Lat. 30°19′.0 N.
Long. 91°46′.5 W.

19. Lat. 29°51′.0 N.
Long. 121°44′.0 W.

20. (*a*) Lat. 50°13′.5 N.
(*b*) Lat. 27°45′.9 N.
(*c*) Lat. 21°45′.5 N.
(*d*) Lat. 34°35′.8 N.
(*e*) Lat. 41°55′.1 N.

21. Lat. 30°05′.0 N.
Long. 95°55′.0 W.

22. (*a*) 66°01′.4 E.
(*b*) 56°10′.3 W.
(*c*) 57°40′.6 E.
(*d*) 26°49′.6 W.
(*e*) 34°18′.4 W.

EXTRACTS FROM
NAUTICAL ALMANAC—1939

SUN, FEBRUARY 939

G. C. T.	Equation of Time	Sun's Declination	Sun's G. H. A.
	Saturday 25		
h	m s	° ′	° ′
0	−13 22.6	−9 30.0	176 39.4
2	13 21.8	9 28.2	206 39.5
4	13 21.1	9 26.3	236 39.7
6	13 20.3	9 24.5	266 39.9
8	13 19.6	9 22.6	296 40.1
10	13 18.8	9 20.8	326 40.3
12	13 18.1	9 18.9	356 40.5
14	13 17.3	9 17.1	26 40.7
16	13 16.5	9 15.2	56 40.9
18	13 15.7	9 13.3	86 41.1
20	13 15.0	9 11.5	116 41.3
22	13 14.2	9 9.6	146 41.5
H. D.	0.4	0.9	... ...
	Sunday 26		
0	−13 13.4	−9 7.8	176 41.6
2	13 12.6	9 5.9	206 41.8
4	13 11.8	9 4.1	236 42.0
6	13 11.0	9 2.2	266 42.2
8	13 10.2	9 0.3	296 42.4
10	13 9.4	8 58.5	326 42.6
12	13 8.6	8 56.6	356 42.8
14	13 7.8	8 54.8	26 43.0
16	13 7.0	8 52.9	56 43.3
18	13 6.1	8 51.0	86 43.5
20	13 5.3	8 49.2	116 43.7
22	13 4.5	8 47.3	146 43.9
H. D.	0 4	0.9	... ...

SEMIDIAMETER

		′
Feb.	1	16.26
	11	16.24
	21	16.20
Mar.	3	16.17

	Corr. to G. H. A.		
Min. or Sec.	Corr. for Minutes	Corr. for 1 hour +Minutes	Corr. for Sec's.
	° ′	° ′	′
0	0 0.0	15 0.0	0.0
1	0 15.0	15 15.0	0.3
2	0 30.0	15 30.0	0.5
3	0 45.0	15 45.0	0.8
4	1 0.0	16 0.0	1.0
5	1 15.0	16 15.0	1.3
6	1 30.0	16 30.0	1.5
7	1 45.0	16 45.0	1.8
8	2 0.0	17 0.0	2.0
9	2 15.0	17 15.0	2.3
10	2 30.0	17 30.0	2.5
11	2 45.0	17 45.0	2.8
12	3 0.0	18 0.0	3.0
13	3 15.0	18 15.0	3.3
14	3 30.0	18 30.0	3.5
15	3 45.0	18 45.0	3.8
16	4 0.0	19 0.0	4.0
17	4 15.0	19 15.0	4.3
18	4 30.0	19 30.0	4.5
19	4 45.0	19 45.0	4.8
20	5 0.0	20 0.0	5.0
21	5 15.0	20 15.0	5.3
22	5 30.0	20 30.0	5.5
23	5 45.0	20 45.0	5.8
24	6 0.0	21 0.0	6.0
25	6 15.0	21 15.0	6.3
26	6 30.0	21 30.0	6.5
27	6 45.0	21 45.0	6.8
28	7 0.0	22 0.0	7.0
29	7 15.0	22 15.0	7.3

	Monday 27		
0	−13 3.6	−8 45.4	176 44.1
2	13 2.8	8 43.6	206 44.3
4	13 2.0	8 41.7	236 44.5
6	13 1.1	8 39.8	266 44.7
8	13 0.3	8 37.9	296 44.9
10	12 59.4	8 36.1	326 45.2
12	12 58.5	8 34.2	356 45.4
14	12 57.7	8 32.3	26 45.6
16	12 56.8	8 30.4	56 45.8
18	12 56.0	8 28.6	86 46.0
20	12 55.1	8 26.7	116 46.2
22	12 54.2	8 24.8	146 46.4
H. D.	0.4	0.9	... ...
	Tuesday 28		
0	−12 53.3	−8 22.9	176 46.7
2	12 52.4	8 21.1	206 46.9
4	12 51.5	8 19.2	236 47.1
6	12 50.6	8 17.3	266 47.3
8	12 49.7	8 15.4	296 47.6
10	12 48.8	8 13.5	326 47.8
12	12 47.9	8 11.6	356 48.0
14	12 47.0	8 9.8	26 48.2
16	12 46.1	8 7.9	56 48.5
18	12 45.2	8 6.0	86 48.7
20	12 44.3	8 4.1	116 48.9
22	−12 43.4	−8 2.2	146 49.2
H. D.	0.5	0.9	... ...

30	7 30.0	22 30.0	7.5
31	7 45.0	22 45.0	7.8
32	8 0.0	23 0.0	8.0
33	8 15.0	23 15.0	8.3
34	8 30.0	23 30.0	8.5
35	8 45.0	23 45.0	8.8
36	9 0.0	24 0.0	9.0
37	9 15.0	24 15.0	9.3
38	9 30.0	24 30.0	9.5
39	9 45.0	24 45.0	9.8
40	10 0.0	25 0.0	10.0
41	10 15.0	25 15.0	10.3
42	10 30.0	25 30.0	10.5
43	10 45.0	25 45.0	10.8
44	11 0.0	26 0.0	11.0
45	11 15.0	26 15.0	11.3
46	11 30.0	26 30.0	11.5
47	11 45.0	26 45.0	11.8
48	12 0.0	27 0.0	12.0
49	12 15.0	27 15.0	12.3
50	12 30.0	27 30.0	12.5
51	12 45.0	27 45.0	12.8
52	13 0.0	28 0.0	13.0
53	13 15.0	28 15.0	13.3
54	13 30.0	28 30.0	13.5
55	13 45.0	28 45.0	13.8
56	14 0.0	29 0.0	14.0
57	14 15.0	29 15.0	14.3
58	14 30.0	29 30.0	14.5
59	14 45.0	29 45.0	14.8
60	15 0.0	30 0.0	15.0

NOTE.—The Equation of Time is to be applied to the G. C. T. in accordance with the sign as given

MOON, 1939

GREENWICH CIVIL TIME

JUNE 10

G. C. T.	Right Ascension	Declination	Greenwich H. A.
h	h m s	° ′	° ′
0	23 3 27	−1 39.9	271 35.3
1	23 5 20	1 29.9	286 9.6
2	23 7 13	1 19.9	300 43.8
3	23 9 6	1 9.8	315 18.0
4	23 10 59	0 59.8	329 52.3
5	23 12 52	0 49.8	344 26.5
6	23 14 45	0 39.7	359 0.7
7	23 16 38	0 29.7	13 34.8
8	23 18 31	0 19.6	28 9.0
9	23 20 24	−0 9.5	42 43.1
10	23 22 18	+0 0.6	57 17.3
11	23 24 11	0 10.6	71 51.4
12	23 26 5	0 20.7	86 25.5
13	23 27 58	0 30.8	100 59.6
14	23 29 52	0 40.9	115 33.6
15	23 31 45	0 51.0	130 7.6
16	23 33 39	1 1.2	144 41.6
17	23 35 33	1 11.3	159 15.6
18	23 37 27	1 21.4	173 49.6
19	23 39 21	1 31.5	188 23.5
20	23 41 16	1 41.6	202 57.4
21	23 43 10	1 51.7	217 31.3
22	23 45 4	2 1.9	232 5.2
23	23 46 59	+2 12.0	246 39.0

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	+0.2	14.6
2	4	0.3	29.1
3	6	0.5	43.7
4	8	0.7	58.3
5	9	0.8	72.8
6	11	1.0	87.4
7	13	1.2	102.0
8	15	1.3	116.5
9	17	1.5	131.1
10	19	1.7	145.7
20	38	3.4	291.4
30	57	5.0	437.0
40	76	6.7	582.7
50	95	+8.4	728.4

JUNE 12

G.C.T.	Right Ascension	Declination	Greenwich H. A.
h	h m s	° ′	° ′
0	0 35 28	+ 6 22.9	250 33.2
1	0 37 27	6 32.8	265 6.0
2	0 39 26	6 42.7	279 38.8
3	0 41 25	6 52.5	294 11.5
4	0 43 24	7 2.3	308 44.1
5	0 45 24	7 12.1	323 16.7
6	0 47 23	7 21.9	337 49.3
7	0 49 23	7 31.7	352 21.8
8	0 51 23	7 41.4	6 54.2
9	0 53 24	7 51.1	21 26.6
10	0 55 24	8 0.8	35 58.9
11	0 57 25	8 10.4	50 31.2
12	0 59 26	8 20.1	65 3.4
13	1 1 27	8 29.7	79 35.5
14	1 3 29	8 39.3	94 7.6
15	1 5 30	8 48.8	108 39.7
16	1 7 32	8 58.3	123 11.6
17	1 9 35	9 7.8	137 43.5
18	1 11 37	9 17.3	152 15.4
19	1 13 40	9 26.7	166 47.2
20	1 15 43	9 36.1	181 18.9
21	1 17 46	9 45.4	195 50.5
22	1 19 50	9 54.8	210 22.1
23	1 21 53	+10 4.0	224 53.6

Multiples of Variation per Minute

m	R.A.	Dec.	H. A.
	s	′	′
1	2	+0.2	14.5
2	4	0.3	29.1
3	6	0.5	43.6
4	8	0.6	58.1
5	10	0.8	72.7
6	12	1.0	87.2
7	14	1.1	101.8
8	16	1.3	116.3
9	18	1.4	130.8
10	20	1.6	145.4
20	40	3.2	290.7
30	61	4.8	436.1
40	81	6.4	581.5
50	101	+8.0	726.8

JUNE 11

0	23 48 53	+2 22.1	261 12.8
1	23 50 48	2 32.2	275 46.6
2	23 52 43	2 42.3	290 20.3
3	23 54 38	2 52.4	304 54.1
4	23 56 33	3 2.6	319 27.7
5	23 58 29	3 12.7	334 1.4
6	0 0 24	3 22.8	348 35.0
7	0 2 19	3 32.8	3 8.6
8	0 4 15	3 42.9	17 42.1
9	0 6 11	3 53.0	32 15.6
10	0 8 7	4 3.1	46 49.1
11	0 10 3	4 13.2	61 22.5
12	0 11 59	4 23.2	75 55.9
13	0 13 56	4 33.3	90 29.2
14	0 15 53	4 43.3	105 2.5
15	0 17 49	4 53.3	119 35.8
16	0 19 46	5 3.3	134 9.0
17	0 21 43	5 13.3	148 42.2
18	0 23 41	5 23.3	163 15.4
19	0 25 38	5 33.3	177 48.5
20	0 27 36	5 43.3	192 21.5
21	0 29 34	5 53.2	206 54.5
22	0 31 32	6 3.1	221 27.5
23	0 33 30	6 13.0	236 0.4
24	0 35 28	+6 22.9	250 33.2

m	R.A. s	Dec. ′	H. A. ′
1	2	+0.2	14.6
2	4	0.3	29.1
3	6	0.5	43.7
4	8	0.7	58.2
5	10	0.8	72.8
6	12	1.0	87.3
7	14	1.2	101.9
8	16	1.3	116.4
9	17	1.5	131.0
10	19	1.7	145.5
20	39	3.4	291.0
30	58	5.0	436.6
40	78	6.7	582.1
50	97	+8.4	727.6

Greenwich Civil Time	Moon's Semidiameter	Moon's Horizontal Parallax
d h	′	′
10 0	14.9	54.5
11 0	15.0	55.0

JUNE 13

0	1 23 57	+10 13.3	239 25.1
1	1 26 2	10 22.5	253 56.5
2	1 28 6	10 31.7	268 27.8
3	1 30 11	10 40.8	282 59.0
4	1 32 16	10 49.9	297 30.2
5	1 34 22	10 58.9	312 1.3
6	1 36 27	11 7.9	326 32.4
7	1 38 33	11 16.9	341 3.3
8	1 40 40	11 25.8	355 34.2
9	1 42 46	11 34.7	10 5.1
10	1 44 53	11 43.5	24 35.8
11	1 47 0	11 52.3	39 6.5
12	1 49 8	12 1.1	53 37.1
13	1 51 16	12 9.7	68 7.6
14	1 53 24	12 18.4	82 38.1
15	1 55 32	12 27.0	97 8.4
16	1 57 41	12 35.5	111 38.7
17	1 59 50	12 44.0	126 9.0
18	2 1 59	12 52.4	140 39.1
19	2 4 8	13 0.8	155 9.2
20	2 6 18	13 9.1	169 39.2
21	2 8 28	13 17.3	184 9.1
22	2 10 39	13 25.5	198 38.9
23	2 12 50	13 33.7	213 8.7
24	2 15 1	+13 41.7	227 38.4

m	R.A. s	Dec. ′	H. A. ′
1	2	+0.1	14.5
2	4	0.3	29.0
3	6	0.4	43.5
4	9	0.6	58.0
5	11	0.7	72.5
6	13	0.9	87.1
7	15	1.0	101.6
8	17	1.2	116.1
9	19	1.3	130.6
10	21	1.5	145.1
20	43	2.9	290.2
30	64	4.4	435.3
40	85	5.8	580.4
50	106	+7.3	725.5

Greenwich Civil Time	Moon's Semidiameter	Moon's Horizontal Parallax
d h	′	′
12 0	15.2	55.5
13 0	15.4	56.3

JUPITER, 1939

GREENWICH CIVIL TIME

Date	Apparent Right Ascension 0h		Apparent Declination 0h		Greenwich H. A. 0h	Var. per Min.	Transit Merid. of Greenwich
	h m s	s	° ′	′	° ′	′	h m
JANUARY							
1	22 11 27	45	−12 16.2	4.2	126 53.0	15.0334	15 30
2	22 12 12	45	12 12.0	4.3	127 41.0	15.0333	15 27
3	22 12 57	45	12 7.7	4.2	128 28.9	15.0332	15 24
4	22 13 42	46	12 3.5	4.4	129 16.7	15.0332	15 21
5	22 14 28	46	11 59.1	4.3	130 4.5	15.0331	15 18
6	22 15 14	46	−11 54.8	4.4	130 52.1	15.0331	15 14
7	22 16 0	46	11 50.4	4.5	131 39.7	15.0330	15 11
8	22 16 46	47	11 45.9	4.4	132 27.2	15.0330	15 8
9	22 17 33	47	11 41.5	4.5	133 14.7	15.0329	15 5
10	22 18 20	48	11 37.0	4.6	134 2.1	15.0329	15 2
11	22 19 8	47	−11 32.4	4.5	134 49.4	15.0328	14 59
12	22 19 55	48	11 27.9	4.6	135 36.6	15.0328	14 56
13	22 20 43	48	11 23.3	4.7	136 23.8	15.0327	14 52
14	22 21 31	49	11 18.6	4.7	137 10.8	15.0327	14 49
15	22 22 20	48	11 13.9	4.7	137 57.9	15.0326	14 46
16	22 23 8	49	−11 9.2	4.7	138 44.9	15.0326	14 43
17	22 23 57	49	11 4.5	4.8	139 31.8	15.0326	14 40
18	22 24 46	50	10 59.7	4.7	140 18.6	15.0325	14 37
19	22 25 36	50	10 55.0	4.9	141 5.4	15.0325	14 34
20	22 26 26	49	10 50.1	4.8	141 52.1	15.0324	14 31

Date	Apparent Right Ascension 0h		Apparent Declination 0h		Greenwich H. A. 0h	Var. per Min.	Transit Merid. of Greenwich
	h m s	s	° ′	′	° ′	′	h
FEBRUARY							
14	22 48 1	54	−8 41.6	5.4	161 6.7	15.0318	13 14
15	22 48 55	53	8 36.2	5.4	161 52.5	15.0318	13 11
16	22 49 48	54	8 30.8	5.5	162 38.2	15.0318	13 8
17	22 50 42	53	8 25.3	5.4	163 24.0	15.0318	13 5
18	22 51 35	54	8 19.9	5.5	164 9.7	15.0318	13 2
19	22 52 29	54	−8 14.4	5.4	164 55.4	15.0317	12 59
20	22 53 23	54	8 9.0	5.5	165 41.1	15.0317	12 56
21	22 54 17	53	8 3.5	5.5	166 26.8	15.0317	12 53
22	22 55 10	54	7 58.0	5.5	167 12.5	15.0317	12 50
23	22 56 4	54	7 52.5	5.5	167 58.2	15.0317	12 46
24	22 56 58	54	−7 47.0	5.5	168 43.8	15.0317	12 44
25	22 57 52	54	7 41.5	5.6	169 29.5	15.0317	12 40
26	22 58 46	54	7 35.9	5.5	170 15.1	15.0317	12 37
27	22 59 40	54	7 30.4	5.5	171 0.8	15.0317	12 34
28	23 0 34	54	−7 24.9	5.6	171 46.4	15.0317	12 31
MARCH							
1	23 1 28	54	−7 19.3	5.5	172 32.1	15.0317	12 28
2	23 2 22	54	7 13.8	5.6	173 17.7	15.0317	12 25

21	22 27 15	50	−10 45.3	4.9	142 38.8	15.0324	14 28
22	22 28 5	51	10 40.4	4.9	143 25.4	15.0324	14 24
23	22 28 56	50	10 35.5	4.9	144 12.0	15.0323	14 21
24	22 29 46	51	10 30.6	5.0	144 58.5	15.0323	14 18
25	22 30 37	51	10 25.6	5.0	145 45.0	15.0323	14 15
26	22 31 28	51	−10 20.6	5.0	146 31.4	15.0322	14 12
27	22 32 19	51	10 15.6	5.1	147 17.8	15.0322	14 9
28	22 33 10	51	10 10.5	5.0	148 4.2	15.0322	14 6
29	22 34 1	52	10 5.5	5.1	148 50.5	15.0321	14 3
30	22 34 53	51	10 0.4	5.1	149 36.7	15.0321	14 0
31	22 35 44	52	− 9 55.3	5.2	150 22.9	15.0321	13 57
			FEBRUARY				
1	22 36 36	52	− 9 50.1	5.1	151 9.1	15.0321	13 54
2	22 37 28	52	− 9 45.0	5.2	151 55.3	15.0320	13 50
3	22 38 20	52	9 39.8	5.2	152 41.4	15.0320	13 48
4	22 39 12	53	9 34.6	5.2	153 27.5	15.0320	13 44
5	22 40 5	52	9 29.4	5.2	154 13.5	15.0320	13 41
6	22 40 57	53	9 24.2	5.3	154 59.5	15.0319	13 38
7	22 41 50	53	− 9 18.9	5.3	155 45.5	15.0319	13 35
8	22 42 43	53	9 13.6	5.3	156 31.5	15.0319	13 32
9	22 43 36	52	9 8.3	5.3	157 17.4	15.0319	13 29
10	22 44 28	54	9 3.0	5.3	158 3.3	15.0319	13 26
11	22 45 22	53	8 57.7	5.4	158 49.2	15.0319	13 23
12	22 46 15	53	− 8 52.3	5.3	159 35.0	15.0318	13 20
13	22 47 8	53	8 47.0	5.4	160 20.9	15.0318	13 17
14	22 48 1	54	8 41.6	5.4	161 6.7	15.0318	13 14
15	22 48 55	53	8 36.2	5.4	161 52.5	15.0318	13 11
16	22 49 48		− 8 30.8		162 38.2	15.0318	13 8

3	23 3 16	54	−7 8.2	5.6	174 3.3	15.0317	12 22
4	23 4 10	54	7 2.6	5.5	174 49.0	15.0317	12 19
5	23 5 4	54	6 57.1	5.6	175 34.6	15.0317	12 16
6	23 5 58	54	6 51.5	5.6	176 20.3	15.0317	12 13
7	23 6 52	54	6 45.9	5.6	177 5.9	15.0317	12 10
8	23 7 46	54	−6 40.3	5.6	177 51.6	15.0317	12 7
9	23 8 40	54	6 34.7	5.6	178 37.2	15.0317	12 4
10	23 9 34	53	6 29.1	5.5	179 22.9	15.0317	12 1
11	23 10 27	54	6 23.6	5.6	180 8.6	15.0317	11 58
12	23 11 21	54	6 18.0	5.6	180 54.2	15.0317	11 55
13	23 12 15	54	−6 12.4	5.6	181 39.9	15.0317	11 52
14	23 13 9	54	6 6.8	5.6	182 25.6	15.0317	11 49
15	23 14 3	53	6 1.2	5.6	183 11.4	15.0318	11 46
16	23 14 56	54	5 55.6	5.6	183 57.1	15.0318	11 43
17	23 15 50	53	5 50.0	5.6	184 42.8	15.0318	11 40
18	23 16 43	54	−5 44.4	5.5	185 28.6	15.0318	11 37
19	23 17 37	53	5 38.9	5.6	186 14.4	15.0318	11 34
20	23 18 30	53	5 33.3	5.6	187 0.1	15.0318	11 30
21	23 19 23	54	5 27.7	5.6	187 45.9	16.0318	11 28
22	23 20 17	53	5 22.1	5.5	188 31.8	15.0318	11 24
23	23 21 10	53	−5 16.6	5.6	189 17.6	15.0319	11 21
24	23 22 3	53	5 11.0	5.5	190 3.5	15.0319	11 18
25	23 22 56	53	5 5.5	5.6	190 49.4	15.0319	11 15
26	23 23 49	53	4 59.9	5.5	191 35.3	15.0319	11 12
27	23 24 42	52	4 54.4	5.5	192 21.3	15.0319	11 9
28	23 25 34	53	−4 48.9	5.5	193 7.2	15.0319	11 6
29	23 26 27	52	4 43.4	5.5	193 53.2	15.0320	11 3
30	23 27 19	52	4 37.9	5.5	194 39.3	15.0320	11 0
31	23 28 11	53	4 32.4	5.5	195 25.3	15.0320	10 57
32	23 29 4		−4 26.9		196 11.4	15.0320	10 54

Polar Semidiameter: Jan. 1, 0′.28; Feb. 1, 0′.26; Mar. 1, 0′.26; Apr. 1, 0′.26 May 1, 0′.27; June 1, 0′.29; July 1, 0′.32

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF PLANETS

Hrs.	°	Variation of Hour Angle per Minute 15'.020	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031	.032	.033	.034	.035	.036	.037	.038	.039	Hrs.
		'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	'	
1	15	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.3	1
2	30	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.6	4.7	2
3	45	3.6	3.8	4.0	4.1	4.3	4.5	4.7	4.9	5.0	5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.8	7.0	3
4	60	4.8	5.0	5.3	5.5	5.8	6.0	6.2	6.5	6.7	7.0	7.2	7.4	7.7	7.9	8.2	8.4	8.6	8.9	9.1	9.4	4
5	75	6.0	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.5	10.8	11.1	11.4	11.7	5
6	90	7.2	7.6	7.9	8.3	8.6	9.0	9.4	9.7	10.1	10.4	10.8	11.2	11.5	11.9	12.2	12.6	13.0	13.3	13.7	14.0	6
7	105	8.4	8.8	9.2	9.7	10.1	10.5	10.9	11.3	11.8	12.2	12.6	13.0	13.4	13.9	14.3	14.7	15.1	15.5	16.0	16.4	7
8	120	9.6	10.1	10.6	11.0	11.5	12.0	12.5	13.0	13.4	13.9	14.4	14.9	15.4	15.8	16.3	16.8	17.3	17.8	18.2	18.7	8
9	135	10.8	11.3	11.9	12.4	13.0	13.5	14.0	14.6	15.1	15.7	16.2	16.7	17.3	17.8	18.4	18.9	19.4	20.0	20.5	21.1	9
10	150	12.0	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	17.4	18.0	18.6	19.2	19.8	20.4	21.0	21.6	22.2	22.8	23.4	10
11	165	13.2	13.9	14.5	15.2	15.8	16.5	17.2	17.8	18.5	19.1	19.8	20.5	21.1	21.8	22.4	23.1	23.8	24.4	25.1	25.7	11
12	180	14.4	15.1	15.8	16.6	17.3	18.0	18.7	19.4	20.2	20.9	21.6	22.3	23.0	23.8	24.5	25.2	25.9	26.6	27.4	28.1	12
13	195	15.6	16.4	17.2	17.9	18.7	19.5	20.3	21.1	21.8	22.6	23.4	24.2	25.0	25.7	26.5	27.3	28.1	28.9	29.6	30.4	13
14	210	16.8	17.6	18.5	19.3	20.2	21.0	21.8	22.7	23.5	24.4	25.2	26.0	26.9	27.7	28.6	29.4	30.2	31.1	31.9	32.8	14
15	225	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2	26.1	27.0	27.9	28.8	29.7	30.6	31.5	32.4	33.3	34.2	35.1	15
16	240	19.2	20.2	21.1	22.1	23.0	24.0	25.0	25.9	26.9	27.8	28.8	29.8	30.7	31.7	32.6	33.6	34.6	35.5	36.5	37.4	16
17	255	20.4	21.4	22.4	23.5	24.5	25.5	26.5	27.5	28.6	29.6	30.6	31.6	32.6	33.7	34.7	35.7	36.7	37.7	38.8	39.8	17
18	270	21.6	22.7	23.8	24.8	25.9	27.0	28.1	29.2	30.2	31.3	32.4	33.5	34.6	35.6	36.7	37.8	38.9	40.0	41.0	42.1	18
19	285	22.8	23.9	25.1	26.2	27.4	28.5	29.6	30.8	31.9	33.1	34.2	35.3	36.5	37.6	38.8	39.9	41.0	42.2	43.3	44.5	19
20	300	24.0	25.2	26.4	27.6	28.8	30.0	31.2	32.4	33.6	34.8	36.0	37.2	38.4	39.6	40.8	42.0	43.2	44.4	45.6	46.8	20
21	315	25.2	26.5	27.7	29.0	30.2	31.5	32.8	34.0	35.3	36.5	37.8	39.1	40.3	41.6	42.8	44.1	45.4	46.6	47.9	49.1	21
22	330	26.4	27.7	29.0	30.4	31.7	33.0	34.3	35.6	37.0	38.3	39.6	40.9	42.2	43.6	44.9	46.2	47.5	48.8	50.2	51.5	22
23	345	27.6	29.0	30.4	31.7	33.1	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.2	45.5	46.9	48.3	49.7	51.1	52.4	53.8	23

Variation of Hour Angle per Minute

Hrs.	15′.040		.041	.042	.043	15′.044		.045	.046	.047	.048	.049	15′.050		.051	.052	.053	.054	.055	Hrs.
	°	′	′	′	′	°	′	′	′	′	′	′	°	′	′	′	′	′	′	
1	15	2.4	2.5	2.5	2.6	15	2.6	2.7	2.8	2.8	2.9	2.9	15	3.0	3.1	3.1	3.2	3.2	3.3	1
2	30	4.8	4.9	5.0	5.2	30	5.3	5.4	5.5	5.6	5.8	5.9	30	6.0	6.1	6.2	6.4	6.5	6.6	2
3	45	7.2	7.4	7.6	7.7	45	7.9	8.1	8.3	8.5	8.6	8.8	45	9.0	9.2	9.4	9.5	9.7	9.9	3
4	60	9.6	9.8	10.1	10.3	60	10.6	10.8	11.0	11.3	11.5	11.8	60	12.0	12.2	12.5	12.7	13.0	13.2	4
5	75	12.0	12.3	12.6	12.9	75	13.2	13.5	13.8	14.1	14.4	14.7	75	15.0	15.3	15.6	15.9	16.2	16.5	5
6	90	14.4	14.8	15.1	15.5	90	15.8	16.2	16.6	16.9	17.3	17.6	90	18.0	18.4	18.7	19.1	19.4	19.8	6
7	105	16.8	17.2	17.6	18.1	105	18.5	18.9	19.3	19.7	20.2	20.6	105	21.0	21.4	21.8	22.3	22.7	23.1	7
8	120	19.2	19.7	20.2	20.6	120	21.1	21.6	22.1	22.6	23.0	23.5	120	24.0	24.5	25.0	25.4	25.9	26.4	8
9	135	21.6	22.1	22.7	23.2	135	23.8	24.3	24.8	25.4	25.9	26.5	135	27.0	27.5	28.1	28.6	29.2	29.7	9
10	150	24.0	24.6	25.2	25.8	150	26.4	27.0	27.6	28.2	28.8	29.4	150	30.0	30.6	31.2	31.8	32.4	33.0	10
11	165	26.4	27.1	27.7	28.4	165	29.0	29.7	30.4	31.0	31.7	32.3	165	33.0	33.7	34.3	35.0	35.6	36.3	11
12	180	28.8	29.5	30.2	31.0	180	31.7	32.4	33.1	33.8	34.6	35.3	180	36.0	36.7	37.4	38.2	38.9	39.6	12
13	195	31.2	32.0	32.8	33.5	195	34.3	35.1	35.9	36.7	37.4	38.2	195	39.0	39.8	40.6	41.3	42.1	42.9	13
14	210	33.6	34.4	35.3	36.1	210	37.0	37.8	38.6	39.5	40.3	41.2	210	42.0	42.8	43.7	44.5	45.4	46.2	14
15	225	36.0	36.9	37.8	38.7	225	39.6	40.5	41.4	42.3	43.2	44.1	225	45.0	45.9	46.8	47.7	48.6	49.5	15
16	240	38.4	39.4	40.3	41.3	240	42.2	43.2	44.2	45.1	46.1	47.0	240	48.0	49.0	49.9	50.9	51.8	52.8	16
17	255	40.8	41.8	42.8	43.9	255	44.9	45.9	46.9	47.9	49.0	50.0	255	51.0	52.0	53.0	54.1	55.1	56.1	17
18	270	43.2	44.3	45.4	46.4	270	47.5	48.6	49.7	50.8	51.8	52.9	270	54.0	55.1	56.2	57.2	58.3	59.4	18
19	285	45.6	46.7	47.9	49.0	285	50.2	51.3	52.4	53.6	54.7	55.9	285	57.0	58.1	59.3	60.4	61.6	62.7	19
20	300	48.0	49.2	50.4	51.6	300	52.8	54.0	55.2	56.4	57.6	58.8	301	0.0	1.2	2.4	3.6	4.8	6.0	20
21	315	50.4	51.7	52.9	54.2	315	55.4	56.7	58.0	59.2	60.5	61.7	316	3.0	4.3	5.5	6.8	8.0	9.3	21
22	330	52.8	54.1	55.4	56.8	330	58.1	59.4	60.7	62.0	63.4	64.7	331	6.0	7.3	8.6	10.0	11.3	12.6	22
23	345	55.2	56.6	58.0	59.3	346	0.7	2.1	3.5	4.9	6.2	7.6	346	9.0	10.4	11.8	13.1	14.5	15.9	23

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF PLANETS

Time	Variation of Hour Angle per Minute									
	14′.98	14′.99	15′.00	15′.01	15′.02	15′.03	15′.04	15′.05	15′.06	15′.07
m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
1	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.0	0 15.1	0 15.1
2	0 30.0	0 30.0	0 30.0	0 30.0	0 30.0	0 30.1	0 30.1	0 30.1	0 30.1	0 30.1
3	0 44.9	0 45.0	0 45.0	0 45.0	0 45.1	0 45.1	0 45.1	0 45.1	0 45.2	0 45.2
4	0 59.9	1 0.0	1 0.0	1 0.0	1 0.1	1 0.1	1 0.2	1 0.2	1 0.2	1 0.3
5	1 14.9	1 14.9	1 15.0	1 15.0	1 15.1	1 15.2	1 15.2	1 15.2	1 15.3	1 15.4
6	1 29.9	1 29.9	1 30.0	1 30.1	1 30.1	1 30.2	1 30.2	1 30.3	1 30.4	1 30.4
7	1 44.9	1 44.9	1 45.0	1 45.1	1 45.1	1 45.2	1 45.3	1 45.3	1 45.4	1 45.5
8	1 59.8	1 59.9	2 0.0	2 0.1	2 0.2	2 0.2	2 0.3	2 0.4	2 0.5	2 0.6
9	2 14.8	2 14.9	2 15.0	2 15.1	2 15.2	2 15.3	2 15.4	2 15.4	2 15.5	2 15.6
10	2 29.8	2 29.9	2 30.0	2 30.1	2 30.2	2 30.3	2 30.4	2 30.5	2 30.6	2 30.7
11	2 44.8	2 44.9	2 45.0	2 45.1	2 45.2	2 45.3	2 45.4	2 45.5	2 45.7	2 45.8
12	2 59.8	2 59.9	3 0.0	3 0.1	3 0.2	3 0.4	3 0.5	3 0.6	3 0.7	3 0.8
13	3 14.7	3 14.9	3 15.0	3 15.1	3 15.3	3 15.4	3 15.5	3 15.6	3 15.8	3 15.9
14	3 29.7	3 29.9	3 30.0	3 30.1	3 30.3	3 30.4	3 30.6	3 30.7	3 30.8	3 31.0
15	3 44.7	3 44.8	3 45.0	3 45.2	3 45.3	3 45.4	3 45.6	3 45.7	3 45.9	3 46.0
16	3 59.7	3 59.8	4 0.0	4 0.2	4 0.3	4 0.5	4 0.6	4 0.8	4 1.0	4 1.1
17	4 14.7	4 14.8	4 15.0	4 15.2	4 15.3	4 15.5	4 15.7	4 15.8	4 16.0	4 16.2
18	4 29.6	4 29.8	4 30.0	4 30.2	4 30.4	4 30.5	4 30.7	4 30.9	4 31.1	4 31.3
19	4 44.6	4 44.8	4 45.0	4 45.2	4 45.4	4 45.6	4 45.8	4 45.9	4 46.1	4 46.3
20	4 59.6	4 59.8	5 0.0	5 0.2	5 0.4	5 0.6	5 0.8	5 1.0	5 1.2	5 1.4
21	5 14.6	5 14.8	5 15.0	5 15.2	5 15.4	5 15.6	5 15.8	5 16.0	5 16.3	5 16.5
22	5 29.6	5 29.8	5 30.0	5 30.2	5 30.4	5 30.7	5 30.9	5 31.1	5 31.3	5 31.5
23	5 44.5	5 44.8	5 45.0	5 45.2	5 45.5	5 45.7	5 45.9	5 46.1	5 46.4	5 46.6
24	5 59.5	5 59.8	6 0.0	6 0.2	6 0.5	6 0.7	6 1.0	6 1.2	6 1.4	6 1.7

Sec.	Corr.
	′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5.3
22	5.5
23	5.8
24	6.0

25	6 14.5	6 14.8	6 15.0	6 15.2	6 15.5	6 15.7	6 16.0	6 16.2	6 16.5	6 16.8	25	6.3
26	6 29.5	6 29.7	6 30.0	6 30.3	6 30.5	6 30.8	6 31.0	6 31.3	6 31.6	6 31.8	26	6.5
27	6 44.5	6 44.7	6 45.0	6 45.3	6 45.5	6 45.8	6 46.1	6 46.3	6 46.6	6 46.9	27	6.8
28	6 59.4	6 59.7	7 0.0	7 0.3	7 0.6	7 0.8	7 1.1	7 1.4	7 1.7	7 2.0	28	7.0
29	7 14.4	7 14.7	7 15.0	7 15.3	7 15.6	7 15.9	7 16.2	7 16.4	7 16.7	7 17.0	29	7.3
30	7 29.4	7 29.7	7 30.0	7 30.3	7 30.6	7 30.9	7 31.2	7 31.5	7 31.8	7 32.1	30	7.5
31	7 44.4	7 44.7	7 45.0	7 45.3	7 45.6	7 45.9	7 46.2	7 46.5	7 46.9	7 47.2	31	7.8
32	7 59.4	7 59.7	8 0.0	8 0.3	8 0.6	8 1.0	8 1.3	8 1.6	8 1.9	8 2.2	32	8.0
33	8 14.3	8 14.7	8 15.0	8 15.3	8 15.7	8 16.0	8 16.3	8 16.6	8 17.0	8 17.3	33	8.3
34	8 29.3	8 29.7	8 30.0	8 30.3	8 30.7	8 31.0	8 31.4	8 31.7	8 32.0	8 32.4	34	8.5
35	8 44.3	8 44.6	8 45.0	8 45.4	8 45.7	8 46.0	8 46.4	8 46.7	8 47.1	8 47.4	35	8.8
36	8 59.3	8 59.6	9 0.0	9 0.4	9 0.7	9 1.1	9 1.4	9 1.8	9 2.2	9 2.5	36	9.0
37	9 14.3	9 14.6	9 15.0	9 15.4	9 15.7	9 16.1	9 16.5	9 16.8	9 17.2	9 17.6	37	9.3
38	9 29.2	9 29.6	9 30.0	9 30.4	9 30.8	9 31.1	9 31.5	9 31.9	9 32.3	9 32.7	38	9.5
39	9 44.2	9 44.6	9 45.0	9 45.4	9 45.8	9 46.2	9 46.6	9 46.9	9 47.3	9 47.7	39	9.8
40	9 59.2	9 59.6	10 0.0	10 0.4	10 0.8	10 1.2	10 1.6	10 2.0	10 2.4	10 2.8	40	10.0
41	10 14.2	10 14.6	10 15.0	10 15.4	10 15.8	10 16.2	10 16.6	10 17.0	10 17.5	10 17.9	41	10.3
42	10 29.2	10 29.6	10 30.0	10 30.4	10 30.8	10 31.3	10 31.7	10 32.1	10 32.5	10 32.9	42	10.5
43	10 44.1	10 44.6	10 45.0	10 45.4	10 45.9	10 46.3	10 46.7	10 47.1	10 47.6	10 48.0	43	10.8
44	10 59.1	10 59.6	11 0.0	11 0.4	11 0.9	11 1.3	11 1.8	11 2.2	11 2.6	11 3.1	44	11.0
45	11 14.1	11 14.6	11 15.0	11 15.4	11 15.9	11 16.3	11 16.8	11 17.2	11 17.7	11 18.2	45	11.3
46	11 29.1	11 29.5	11 30.0	11 30.5	11 30.9	11 31.4	11 31.8	11 32.3	11 32.8	11 33.2	46	11.5
47	11 44.1	11 44.5	11 45.0	11 45.5	11 45.9	11 46.4	11 46.9	11 47.3	11 47.8	11 48.3	47	11.8
48	11 59.0	11 59.5	12 0.0	12 0.5	12 1.0	12 1.4	12 1.9	12 2.4	12 2.9	12 3.4	48	12.0
49	12 14.0	12 14.5	12 15.0	12 15.5	12 16.0	12 16.5	12 17.0	12 17.4	12 17.9	12 18.4	49	12.3
50	12 29.0	12 29.5	12 30.0	12 30.5	12 31.0	12 31.5	12 32.0	12 32.5	12 33.0	12 33.5	50	12.5
51	12 44.0	12 44.5	12 45.0	12 45.5	12 46.0	12 46.5	12 47.0	12 47.5	12 48.1	12 48.6	51	12.8
52	12 59.0	12 59.5	13 0.0	13 0.5	13 1.0	13 1.6	13 2.1	13 2.6	13 3.1	13 3.6	52	13.0
53	13 13.9	13 14.5	13 15.0	13 15.5	13 16.1	13 16.6	13 17.1	13 17.6	13 18.2	13 18.7	53	13.3
54	13 28.9	13 29.5	13 30.0	13 30.5	13 31.1	13 31.6	13 32.2	13 32.7	13 33.2	13 33.8	54	13.5
55	13 43.9	13 44.4	13 45.0	13 45.6	13 46.1	13 46.6	13 47.2	13 47.7	13 48.3	13 48.8	55	13.8
56	13 58.9	13 59.4	14 0.0	14 0.6	14 1.1	14 1.7	14 2.2	14 2.8	14 3.4	14 3.9	56	14.0
57	14 13.9	14 14.4	14 15.0	14 15.6	14 16.1	14 16.7	14 17.3	14 17.8	14 18.4	14 19.0	57	14.3
58	14 28.8	14 29.4	14 30.0	14 30.6	14 31.2	14 31.7	14 32.3	14 32.9	14 33.5	14 34.1	58	14.5
59	14 43.8	14 44.4	14 45.0	14 45.6	14 46.2	14 46.8	14 47.4	14 47.9	14 48.5	14 40.1	59	14.8
60	14 58.8	14 59.4	15 0.0	15 0.6	15 1.2	15 1.8	15 2.4	15 3.0	15 3 6	15 4.2	60	15.0

STARS, OCTOBER 1939

GREENWICH CIVIL TIME

Star	Alphecca α Cor. Bor. Mag. 2.3	Dschubba δ Scorpii Mag. 2.5	Antares α Scorpii Mag. 1.2	α Tri. Aus. Mag. 1.9	Sabik η Ophiuchi Mag. 2.6	Shaula λ Scorpii Mag. 1.7	Rasalague α Ophiuchi Mag. 2.1	Etamin γ Draconis Mag. 2.4	Kaus Austr. ε Sagittarii Mag. 2.0
Date	Greenwich Hour Angle for 0^h Greenwich Civil Time								
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
13	147 37.5	141 27.9	134 13.8	130 5.5	123 55.6	118 16.6	117 37.3	111 51.4	105 36.6
14	148 36.7	142 27.1	135 12.9	131 4.6	124 54.7	119 15.8	118 36.5	112 50.6	106 35.8
15	149 35.8	143 26.2	136 12.1	132 3.8	125 53.9	120 14.9	119 35.6	113 49.7	107 35.0
16	150 35.0	144 25.4	137 11.2	133 2.9	126 53.0	121 14.1	120 34.8	114 48.8	108 34.1
17	151 34.1	145 24.5	138 10.3	134 2.1	127 52.1	122 13.2	121 33.9	115 48.0	109 33.3
18	152 33.2	146 23.6	139 9.5	135 1.2	128 51.3	123 12.3	122 33.1	116 47.1	110 32.4
19	153 32.4	147 22.8	140 8.6	136 0.3	129 50.4	124 11.5	123 32.2	117 46.3	111 31.5
20	154 31.5	148 21.9	141 7.8	136 59.5	130 49.6	125 10.6	124 31.3	118 45.4	112 30.7
21	155 30.7	149 21.1	142 6.9	137 58.6	131 48.7	126 9.8	125 30.5	119 44.6	113 29.8
22	156 29.8	150 20.2	143 6.0	138 57.8	132 47.9	127 8.9	126 29.6	120 43.7	114 29.0
23	157 28.9	151 19.3	144 5.2	139 56.9	133 47.0	128 8.1	127 28.8	121 42.9	115 28.1
24	158 28.1	152 18.5	145 4.3	140 56.1	134 46.1	129 7.2	128 27.9	122 42.0	116 27.3
25	159 27.2	153 17.6	146 3.5	141 55.2	135 45.3	130 6.3	129 27.0	123 41.2	117 26.4
26	160 26.4	154 16.8	147 2.6	142 54.4	136 44.4	131 5.5	130 26.2	124 40.3	118 25.5
27	161 25.5	155 15.9	148 1.7	143 53.5	137 43.6	132 4.6	131 25.3	125 39.5	119 24.7
28	162 24.6	156 15.0	149 0.9	144 52.6	138 42.7	133 3.8	132 24.5	126 38.6	120 23.8
29	163 23.8	157 14.2	150 0.0	145 51.8	139 41.8	134 2.9	133 23.6	127 37.7	121 23.0
30	164 22.9	158 13.3	150 59.2	146 50.9	140 41.0	135 2.1	134 22.8	128 36.9	122 22.1
31	165 22.1	159 12.5	151 58.3	147 50.1	141 40.1	136 1.2	135 21.9	129 36.0	123 21.3

Star	Vega α Lyræ Mag. 0.1	Nunki σ Sagittarii Mag. 2.1	Altair α Aquilæ Mag. 0.9	Peacock α Pavonis Mag. 2.1	Deneb α Cygni Mag. 1.3	Enif ε Pegasi Mag. 2.5	Al Na'ir α Gruis Mag. 2.2	Fomalhaut α Pis. Aus. Mag. 1.3	Markab α Pegasi Mag. 2.6
Oct. 1	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s
R. A.	18 34 54.2	18 51 32.5	19 47 51.5	20 20 55.0	20 39 24.2	21 41 15.0	22 4 28.4	22 54 21.1	23 1 47.2
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Dec.	+38 44.0	−26 22.3	+8 42.8	−56 55.8	+45 4.3	+9 36.2	−47 15.1	−29 56.4	+14 53.1
	h m	h m	h m	h m	h m	h m	h m	h m	h m
Transit	17 57	18 13	19 9	19 42	20 1	21 2	21 26	22 15	22 23

Date	Greenwich Hour Angle for 0^h Greenwich Civil Time								
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
1	90 6.1	85 56.6	71 51.8	63 36.0	58 58.7	43 30.9	37 42.6	25 14.4	23 22.9
2	91 5.3	86 55.7	72 51.0	64 35.1	59 57.8	44 30.0	38 41.8	26 13.6	24 22.0
3	92 4.4	87 54.9	73 50.1	65 34.2	60 57.0	45 29.2	39 40.9	27 12.7	25 21.2
4	93 3.6	88 54.0	74 49.3	66 33.4	61 56.1	46 28.4	40 40.0	28 11.8	26 20.3
5	94 2.7	89 53.2	75 48.4	67 32.5	62 55.2	47 27.5	41 39.2	29 11.0	27 19.5
6	95 1.9	90 52.3	76 47.5	68 31.7	63 54.4	48 26.7	42 38.3	30 10.1	28 18.6
7	96 1.0	91 51.4	77 46.7	69 30.8	64 53.5	49 25.8	43 37.5	31 9.3	29 17.7
8	97 0.2	92 50.6	78 45.8	70 30.0	65 52.7	50 24.9	44 36.6	32 8.4	30 16.9
9	97 59.3	93 49.7	79 45.0	71 29.1	66 51.8	51 24.1	45 35.8	33 7.6	31 16.0
10	98 58.4	94 48.9	80 44.1	72 28.3	67 51.0	52 23.2	46 34.9	34 6.7	32 15.2
11	99 57.6	95 48.0	81 43.3	73 27.4	68 50.1	53 22.4	47 34.0	35 5.8	33 14.3
12	100 56.7	96 47.2	82 42.4	74 26.6	69 49.3	54 21.5	48 33.2	36 5.0	34 13.4
13	101 55.9	97 46.3	83 41.5	75 25.7	70 48.4	55 20.6	49 32.3	37 4.1	35 12.6
14	102 55.0	98 45.4	84 40.7	76 24.8	71 47.6	56 19.8	50 31.5	38 3.3	36 11.7
15	103 54.2	99 44.6	85 39.8	77 24.0	72 46.7	57 18.9	51 30.6	39 2.4	37 10.9
16	104 53.3	100 43.7	86 39.0	78 23.1	73 45.8	58 18.1	52 29.8	40 1.5	38 10.0
17	105 52.5	101 42.9	87 38.1	79 22.3	74 45.0	59 17.2	53 28.9	41 0.7	39 9.1
18	106 51.6	102 42.0	88 37.3	80 21.4	75 44.1	60 16.4	54 28.0	41 59.8	40 8.3
19	107 50.8	103 41.2	89 36.4	81 20.6	76 43.3	61 15.5	55 27.2	42 59.0	41 7.4
20	108 49.9	104 40.3	90 35.5	82 19.7	77 42.4	62 14.6	56 26.3	43 58.1	42 6.6
21	109 49.0	105 39.4	91 34.7	83 18.9	78 41.6	63 13.8	57 25.5	44 57.2	43 5.7
22	110 48.2	106 38.6	92 33.8	84 18.0	79 40.7	64 12.9	58 24.6	45 56.4	44 4.8
23	111 47.3	107 37.7	93 33.0	85 17.2	80 39.9	65 12.1	59 23.8	46 55.5	45 4.0
24	112 46.5	108 36.9	94 32.1	86 16.3	81 39.0	66 11.2	60 22.9	47 54.7	46 3.1
25	113 45.6	109 36.0	95 31.3	87 15.5	82 38.1	67 10.4	61 22.0	48 53.8	47 2.3
26	114 44.8	110 35.2	96 30.4	88 14.6	83 37.3	68 9.5	62 21.2	49 53.0	48 1.4
27	115 43.9	111 34.3	97 29.5	89 13.7	84 36.4	69 8.6	63 20.3	50 52.1	49 0.5
28	116 43.1	112 33.4	98 28.7	90 12.9	85 35.6	70 7.8	64 19.5	51 51.2	49 59.7
29	117 42.2	113 32.6	99 27.8	91 12.0	86 34.7	71 6.9	65 18.6	52 50.4	50 58.8
30	118 41.4	114 31.7	100 27.0	92 11.2	87 33.9	72 6.1	66 17.8	53 49.5	51 58.0
31	119 40.5	115 30.9	101 26.1	93 10.3	88 33.0	73 5.2	67 16.9	54 48.7	52 57.1

CORRECTION TO BE ADDED TO TABULATED GREENWICH HOUR ANGLE OF STARS

Min.	Hours of Greenwich Civil Time							
	0h	1h	2h	3h	4h	5h	6h	7h
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0 0.0	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2
1	0 15.0	15 17.5	30 19.9	45 22.4	60 24.9	75 27.4	90 29.8	105 32.3
2	0 30.1	15 32.5	30 35.0	45 37.5	60 39.9	75 42.4	90 44.9	105 47.3
3	0 45.1	15 47.6	30 50.1	45 52.5	60 55.0	75 57.4	90 59.9	106 2.4
4	1 0.2	16 2.6	31 5.1	46 7.6	61 10.0	76 12.5	91 14.9	106 17.4
5	1 15.2	16 17.7	31 20.1	46 22.6	61 25.1	76 27.5	91 30.0	106 32.5
6	1 30.2	16 32.7	31 35.2	46 37.6	61 40.1	76 42.6	91 45.0	106 47.5
7	1 45.3	16 47.8	31 50.2	46 52.7	61 55.1	76 57.6	92 0.1	107 2.5
8	2 0.3	17 2.8	32 5.3	47 7.7	62 10.2	77 12.6	92 15.1	107 17.6
9	2 15.4	17 17.8	32 20.3	47 22.8	62 25.2	77 27.7	92 30.2	107 32.6
10	2 30.4	17 32.9	32 35.3	47 37.8	62 40.3	77 42.7	92 45.2	107 47.7
11	2 45.5	17 47.9	32 50.4	47 52.8	62 55.3	77 57.8	93 0.2	108 2.7
12	3 0.5	18 3.0	33 5.4	48 7.9	63 10.3	78 12.8	93 15.3	108 17.7
13	3 15.5	18 18.0	33 20.5	48 22.9	63 25.4	78 27.9	93 30.3	108 32.8
14	3 30.6	18 33.0	33 35.5	48 38.0	63 40.4	78 42.9	93 45.4	108 47.8
15	3 45.6	18 48.1	33 50.5	48 53.0	63 55.5	78 57.9	94 0.4	109 2.9
16	4 0.7	19 3.1	34 5.6	49 8.0	64 10.5	79 13.0	94 15.4	109 17.9
17	4 15.7	19 18.2	34 20.6	49 23.1	64 25.6	79 28.0	94 30.5	109 32.9
18	4 30.7	19 33.2	34 35.7	49 38.1	64 40.6	79 43.1	94 45.5	109 48.0
19	4 45.8	19 48.2	34 50.7	49 53.2	64 55.6	79 58.1	95 0.6	110 3.0
20	5 0.8	20 3.3	35 5.7	50 8.2	65 10.7	80 13.1	95 15.6	110 18.1
21	5 15.9	20 18.3	35 20.8	50 23.3	65 25.7	80 28.2	95 30.6	110 33.1
22	5 30.9	20 33.4	35 35.8	50 38.3	65 40.8	80 43.2	95 45.7	110 48.2
23	5 45.9	20 48.4	35 50.9	50 53.3	65 55.8	80 58.3	96 0.7	111 3.2
24	6 1.0	21 3.4	36 5.9	51 8.4	66 10.8	81 13.3	96 15.8	111 18.2

Sec.	Corr.
	′
0	0.0
1	0.3
2	0.5
3	0.8
4	1.0
5	1.3
6	1.5
7	1.8
8	2.0
9	2.3
10	2.5
11	2.8
12	3.0
13	3.3
14	3.5
15	3.8
16	4.0
17	4.3
18	4.5
19	4.8
20	5.0
21	5.3
22	5.5
23	5.8
24	6.0

25	6 16.0	21 18.5	36 21.0	51 23.4	66 25.9	81 28.3	96 30.8	111 33.3	25	6.3
26	6 31.1	21 33.5	36 36.0	51 38.5	66 40.9	81 43.4	96 45.8	111 48.3	26	6.5
27	6 46.1	21 48.6	36 51.0	51 53.5	66 56.0	81 58.4	97 0.9	112 3.4	27	6.8
28	7 1.1	22 3.6	37 6.1	52 8.5	67 11.0	82 13.5	97 15.9	112 18.4	28	7.0
29	7 16.2	22 18.7	37 21.1	52 23.6	67 26.0	82 28.5	97 31.0	112 33.4	29	7 3
30	7 31.2	22 33.7	37 36.2	52 38.6	67 41.1	82 43.6	97 46.0	112 48.5	30	7.5
31	7 46.3	22 48.7	37 51.2	52 53.7	67 56.1	82 58.6	98 1.1	113 3.5	31	7.8
32	8 1.3	23 3.8	38 6.2	53 8.7	68 11.2	83 13.6	98 16.1	113 18.6	32	8.0
33	8 16.4	23 18.8	38 21.3	53 23.7	68 26.2	83 28.7	98 31.1	113 33.6	33	8.3
34	8 31.4	23 33.9	38 36.3	53 38.8	68 41.2	83 43.7	98 46.2	113 48.6	34	8.5
35	8 46.4	23 48.9	38 51.4	53 53.8	68 56.3	83 58.8	99 1.2	114 3.7	35	8.8
36	9 1.5	24 3.9	39 6.4	54 8.9	69 11.3	84 13.8	99 16.3	114 18.7	36	9.0
37	9 16.5	24 19.0	39 21.4	54 23.9	69 26.4	84 28.8	99 31.3	114 33.8	37	9.3
38	9 31.6	24 34.0	39 36.5	54 39.0	69 41.4	84 43.9	99 46.3	114 48.8	38	9.5
39	9 46.6	24 49.1	39 51.5	54 54.0	69 56.5	84 58.9	100 1.4	115 3.9	39	9.8
40	10 1.6	25 4.1	40 6.6	55 9.0	70 11.5	85 14.0	100 16.4	115 18.9	40	10.0
41	10 16.7	25 19.1	40 21.6	55 24.1	70 26.5	85 29.0	100 31.5	115 33.9	41	10.3
42	10 31.7	25 34.2	40 36.7	55 39.1	70 41.6	85 44.0	100 46 5	115 49.0	42	10.5
43	10 46.8	25 49.2	40 51.7	55 54.2	70 56.6	85 59.1	101 1.5	116 4.0	43	10.8
44	11 1.8	26 4.3	41 6.7	56 9.2	71 11.7	86 14.1	101 16.6	116 19.1	44	11.0
45	11 16.8	26 19.3	41 21.8	56 24.2	71 26.7	86 29.2	101 31.6	116 34.1	45	11.3
46	11 31.9	26 34.4	41 36.8	56 39.3	71 41.7	86 44.2	101 46.7	116 49.1	46	11.5
47	11 46.9	26 49.4	41 51.9	56 54.3	71 56.8	86 59.2	102 1.7	117 4.2	47	11.8
48	12 2.0	27 4.4	42 6.9	57 9.4	72 11.8	87 14.3	102 16.8	117 19.2	48	12.0
49	12 17.0	27 19.5	42 21.9	57 24.4	72 26.9	87 29.3	102 31.8	117 34.3	49	12.3
50	12 32.1	27 34.5	42 37.0	57 39.4	72 41.9	87 44.4	102 46.8	117 49.3	50	12.5
51	12 47.1	27 49.6	42 52.0	57 54.5	72 56.9	87 59.4	103 1.9	118 4.3	51	12.8
52	13 2.1	28 4.6	43 7.1	58 9.5	73 12.0	88 14.5	103 16.9	118 19.4	52	13.0
53	13 17.2	28 19.6	43 22.1	58 24.6	73 27.0	88 29.5	103 32.0	118 34.4	53	13.3
54	13 32.2	28 34.7	43 37.1	58 39.6	73 42.1	88 44.5	103 47.0	118 49.5	54	13.5
55	13 47.3	28 49.7	43 52.2	58 54.6	73 57.1	88 59.6	104 2.0	119 4.5	55	13.8
56	14 2.3	29 4.8	44 7.2	59 9.7	74 12.2	89 14.6	104 17.1	119 19.5	56	14.0
57	14 17.3	29 19.8	44 22.3	59 24.7	74 27.2	89 29.7	104 32.1	119 34.6	57	14.3
58	14 32.4	29 34.8	44 37.3	59 39.8	74 42.2	89 44.7	104 47.2	119 49.6	58	14.5
59	14 47.4	29 49.9	44 52.4	59 54.8	74 57.3	89 59.7	105 2.2	120 4.7	59	14.8
60	15 2.5	30 4.9	45 7.4	60 9.9	75 12.3	90 14.8	105 17.2	120 19.7	60	15.0

CORRECTIONS TO BE APPLIED TO THE OBSERVED ALTITUDE OF A STAR OR OF THE SUN'S LOWER LIMB, TO FIND THE TRUE ALTITUDE

TABLE A

Observed Altitude	☉ Sun's Corr.	★ Star's Corr.
° ′	′	′
6 30	+ 8.2	−7.9
6 40	8.4	7.7
6 50	8.6	7.6
7 0	8.7	7.4
7 10	8.9	7.2
7 20	+ 9.0	−7.1
7 30	9.2	7.0
7 40	9.3	6.8
7 50	9.5	6.7
8 0	9.6	6.6
8 10	+ 9.7	−6.4
8 20	9.8	6.3
8 30	10.0	6.2
8 40	10.1	6.1
8 50	10.2	6.0
9 0	+10.3	−5.9
9 20	10.5	5.7
9 40	10.6	5.5
10 0	10.8	5.3
10 20	11.0	5.2

TABLE B

Date	☉ Additional Sun's Corr.
	′
Jan. 1	+0.3
15	+0.3
Feb. 1	+0.3
15	+0.2
Mar. 1	+0.2
15	+0.1
Apr. 1	0.0
15	0.0
May 1	−0.1
15	−0.1
June 1	−0.2
15	−0.2

TABLE C

Correction for Height of Eye			
Height of Eye (feet)	Corr.	Height of Eye (feet)	Corr.
	′		′
0	0.0	100	− 9.8
1	−1.0	150	12.0
2	1.4	200	13.9
3	1.7	250	15.5
4	2.0	300	17.0
5	−2.2	350	−18.3
6	2.4	400	19.6
7	2.6	450	20.8
8	2.8	500	21.9
9	2.9	550	23.0
10	−3.1	600	−24.0
11	3.2	650	25.0
12	3.4	700	25.9
13	3.5	750	26.8
14	3.7	800	27.7
15	−3.8	850	−28.6
16	3.9	900	29.4
17	4.0	950	30.2
18	4.1	1000	31.0
19	4.3	1050	31.8

10 40	+11.2	−5.0
11 0	11.3	4.9
11 30	11.5	4.7
12 0	11.7	4.5
12 30	11.9	4.3
13 0	+12.0	−4.1
13 30	12.2	4.0
14 0	12.3	3.8
15 0	12.6	3.6
16 0	12.8	3.4
17 0	+13.0	−3.2
18 0	13.2	3.0
19 0	13.3	2.8
20 0	13.5	2.6
22 0	13.7	2.4
24 0	+14.0	−2.2
26 0	14.1	2.0
28 0	14.3	1.8
30 0	14.4	1.7
32 0	14.6	1.6
34 0	+14.7	−1.4
36 0	14.8	1.3
38 0	14.9	1.3
40 0	15.0	1.2
45 0	15.1	1.0
50 0	+15.3	−0.8
55 0	15.4	0.7
60 0	15.5	0.6
65 0	15.6	0.5
70 0	15.7	0.4
75 0	+15.8	−0.3
80 0	15.8	0.2
85 0	15.9	−0.1
90 0	+16.0	0.0

July	1	−0.2
	15	−0.2
Aug.	1	−0.2
	15	−0.2
Sept.	1	−0.1
	15	−0.1
Oct.	1	0.0
	15	+0.1
Nov.	1	+0.2
	15	+0.2
Dec.	1	+0.3
	15	+0.3
	31	+0.3

20	−4.4	1100	−32.5
21	4.5	1150	33.2
22	4.6	1200	34.0
23	4.7	1250	34.6
24	4.8	1300	35.3
25	−4.9	1350	−36.0
26	5.0	1400	36.7
27	5.1	1450	37.3
28	5.2	1500	38.0
29	5.3	1550	38.6
30	−5.4	1600	−39.2
31	5.4	1650	39.8
32	5.5	1700	40.5
33	5.6	1800	41.6
34	5.7	1900	42.7
35	−5.8	2000	−43.8
37	6.0	2100	44.9
39	6.1	2200	46.0
41	6.3	2300	47.0
43	6.4	2400	47.9
45	−6.6	2500	−49.0
47	6.7	2600	50.0
49	6.9	2700	50.9
51	7.0	2800	51.9
53	7.1	2900	52.8
55	−7.3	3000	−53.7
60	7.6	3100	54.6
65	7.9	3200	55.4
70	8.2	3300	56.3
75	8.5	3400	57.1
80	−8.8	3500	−58.0
85	9.0	3600	58.8
90	9.3	3700	59.6
95	9.6	3800	60.4
100	−9.8	4000	−62.0

TABLE D

CORRECTION TO THE OBSERVED ALTITUDE OF THE MOON

FOR REFRACTION, PARALLAX, AND SEMIDIAMETER

Lower Limb									Upper Limb								
Obs. Alt. Lower Limb	Horizontal Parallax								Obs. Alt. Upper Limb	Horizontal Parallax							
	54′	55′	56′	57′	58′	59′	60′	61′		54′	55′	56′	57′	58′	59′	60′	61′
°	′	′	′	′	′	′	′	′	°	′	′	′	′	′	′	′	′
5.5	+59.6	+60.9	+62.1	+63.4	+64.7	+66.0	+67.3	+68.5	5.5	+29.4	+30.2	+30.9	+31.6	+32.3	+33.0	+33.7	+34.4
6.0	60.2	61.4	62.7	64.0	65.3	66.5	67.8	69.1	6.0	30.1	30.8	31.5	32.3	33.0	33.7	34.4	35.1
6.5	60.7	61.9	63.2	64.5	65.8	67.0	68.3	69.6	6.5	30.7	31.4	32.1	32.8	33.5	34.3	35.0	35.7
7.0	61.1	62.4	63.6	64.9	66.2	67.4	68.7	70.0	7.0	31.2	31.9	32.6	33.3	34.0	34.8	35.5	36.2
7.5	61.5	62.7	64.0	65.3	66.5	67.8	69.1	70.4	7.5	31.6	32.3	33.0	33.7	34.5	35.2	35.9	36.6
8.0	+61.8	+63.1	+64.3	+65.6	+66.9	+68.1	+69.4	+70.7	8.0	+32.0	+32.7	+33.4	+34.1	+34.8	+35.5	+36.3	+37.0
8.5	62.1	63.3	64.6	65.9	67.1	68.4	69.7	70.9	8.5	32.3	33.0	33.7	34.4	35.1	35.9	36.6	37.3
9.0	62.3	63.6	64.8	66.1	67.4	68.6	69.9	71.1	9.0	32.6	33.3	34.0	34.7	35.4	36.1	36.8	37.5
9.5	62.5	63.8	65.0	66.3	67.6	68.8	70.1	71.3	9.5	32.8	33.5	34.2	34.9	35.6	36.3	37.1	37.8
10.0	62.7	64.0	65.2	66.5	67.7	69.0	70.3	71.5	10.0	33.0	33.7	34.4	35.1	35.8	36.5	37.3	38.0
11	+63.0	+64.2	+65.5	+66.7	+68.0	+69.3	+70.5	+71.8	11	+33.3	+34.0	+34.7	+35.4	+36.2	+36.9	+37.6	+38.3
12	63.2	64.4	65.7	66.9	68.2	69.5	70.7	72.0	12	33.6	34.3	35.0	35.7	36.4	37.1	37.8	38.5
13	63.3	64.6	65.8	67.0	68.3	69.6	70.8	72.1	13	33.7	34.4	35.1	35.8	36.5	37.2	37.9	38.6
14	63.4	64.6	65.9	67.1	68.4	69.6	70.9	72.1	14	33.8	34.5	35.2	35.9	36.6	37.3	38.0	38.7
15	63.4	64.6	65.9	67.1	68.4	69.6	70.9	72.1	15	33.8	34.5	35.2	35.9	36.6	37.3	38.0	38.7
16	+63.4	+64.6	+65.8	+67.1	+68.3	+69.6	+70.8	+72.0	16	+33.8	+34.5	+35.2	+35.9	+36.6	+37.3	+38.0	+38.6
17	63.3	64.5	65.8	67.0	68.2	69.5	70.7	71.9	17	33.8	34.5	35.1	35.8	36.5	37.2	37.9	38.6
18	63.2	64.4	65.6	66.9	68.1	69.3	70.6	71.8	18	33.7	34.3	35.0	35.7	36.4	37.1	37.7	38.4
19	63.1	64.3	65.5	66.7	67.9	69.2	70.4	71.6	19	33.5	34.2	34.9	35.6	36.2	36.9	37.6	38.2
20	62.9	64.1	65.3	66.5	67.8	69.0	70.2	71.4	20	33.4	34.0	34.7	35.4	36.0	36.7	37.4	38.1

21	+62.7	+63.9	+65.1	+66.3	+67.5	+68.7	+70.0	+71.2	21	+33.2	+33.9	+34.5	+35.2	+35.8	+36.5	+37.2	+37.8
22	62.5	63.7	64.9	66.1	67.3	68.5	69.7	70.9	22	33.0	33.6	34.3	34.9	35.6	36.3	36.9	37.6
23	62.2	63.4	64.6	65.9	67.0	68.2	69.4	70.6	23	32.7	33.4	34.0	34.7	35.3	36.0	36.6	37.3
24	62.0	63.1	64.3	65.5	66.7	67.9	69.1	70.3	24	32.5	33.1	33.7	34.4	35.0	35.7	36.3	37.0
25	61.7	62.9	64.0	65.2	66.4	67.6	68.8	69.9	25	32.2	32.8	33.4	34.1	34.7	35.4	36.0	36.6
26	+61.3	+62.5	+63.7	+64.9	+66.0	+67.2	+68.4	+69.6	26	+31.9	+32.5	+33.1	+33.7	+34.4	+35.0	+35.6	+36.2
27	61.0	62.2	63.3	64.5	65.7	66.8	68.0	69.2	27	31.5	32.1	32.8	33.4	34.0	34.6	35.2	35.9
28	60.7	61.8	63.0	64.1	65.3	66.4	67.6	68.8	28	31.2	31.8	32.4	33.0	33.6	34.2	34.9	35.5
29	60.3	61.4	62.6	63.7	64.9	66.0	67.2	68.4	29	30.8	31.4	32.0	32.6	33.2	33.8	34.4	35.0
30	59.9	61.0	62.2	63.3	64.4	65.6	66.7	67.9	30	30.4	31.0	31.6	32.2	32.8	33.4	34.0	34.6
31	+59.5	+60.6	+61.7	+62.9	+64.0	+65.1	+66.3	+67.4	31	+30.0	+30.6	+31.2	+31.8	+32.3	+32.9	+33.5	+34.1
32	59.0	60.2	61.3	62.4	63.5	64.7	65.8	66.9	32	29.6	30.1	30.7	31.3	31.9	32.5	33.0	33.6
33	58.6	59.7	60.8	61.9	63.1	64.2	65.3	66.4	33	29.1	29.7	30.3	30.8	31.4	32.0	32.5	33.1
34	58.1	59.2	60.3	61.4	62.5	63.6	64.8	65.9	34	28.7	29.2	29.8	30.3	30.9	31.5	32.0	32.6
35	57.7	58.7	59.8	60.9	62.0	63.1	64.2	65.3	35	28.2	28.7	29.3	29.8	30.4	30.9	31.5	32.0
36	+57.2	+58.2	+59.3	+60.4	+61.5	+62.6	+63.7	+64.7	36	+27.7	+28.2	+28.8	+29.3	+29.8	+30.4	+30.9	+31.5
37	56.7	57.7	58.8	59.8	60.9	62.0	63.1	64.2	37	27.2	27.7	28.2	28.8	29.3	29.8	30.3	30.9
38	56.1	57.2	58.2	59.3	60.4	61.4	62.5	63.6	38	26.7	27.2	27.7	28.2	28.7	29.2	29.7	30.3
39	55.6	56.6	57.7	58.7	59.8	60.8	61.9	62.9	39	26.1	26.6	27.1	27.6	28.1	28.6	29.1	29.6
40	55.0	56.1	57.1	58.1	59.2	60.2	61.3	62.3	40	25.6	26.1	26.6	27.1	27.6	28.0	28.5	29.0
41	+54.4	+55.5	+56.5	+57.5	+58.6	+59.6	+60.6	+61.6	41	+25.0	+25.5	+26.0	+26.4	+26.9	+27.4	+27.9	+28.4
42	53.9	54.9	55.9	56.9	57.9	59.0	60.0	61.0	42	24.4	24.9	25.4	25.8	26.3	26.8	27.2	27.7
43	53.3	54.3	55.3	56.3	57.3	58.3	59.3	60.3	43	23.8	24.3	24.7	25.2	25.6	26.1	26.6	27.0
44	52.7	53.7	54.6	55.6	56.6	57.6	58.6	59.6	44	23.2	23.6	24.1	24.6	25.0	25.4	25.9	26.3
45	52.0	53.0	54.0	55.0	56.0	56.9	57.9	58.9	45	22.6	23.0	23.4	23.9	24.3	24.7	25.2	25.6
46	+51.4	+52.4	+53.3	+54.3	+55.3	+56.2	+57.2	+58.2	46	+21.9	+22.4	+22.8	+23.2	+23.6	+24.0	+24.5	+24.9

For Height of Eye Correction see Table C

TABLE E

BUBBLE SEXTANT CORRECTION TO OBSERVED ALTITUDE OF SUN OR STAR

FOR REFRACTION AND PARALLAX

Observed Altitude	Sun's Correction	Star's Correction	Observed Altitude	Sun's Correction	Star's Correction	Observed Altitude	Sun's Correction	Star's Correction
° ′	′	′	° ′	′	′	° ′	′	′
6 30	−7.8	−7.9	10 0	−5.2	−5.3	24 0	−2.0	−2.2
6 40	7.6	7.7	10 20	5.0	5.2	26 0	1.9	2.0
6 50	7.4	7.6	10 40	4.9	5.0	28 0	1.7	1.8
7 0	7.3	7.4	11 0	4.7	4.9	30 0	1.6	1.7
7 10	7.1	7.2	11 30	4.5	4.7	32 0	1.4	1.6
7 20	−7.0	−7.1	12 0	−4.3	−4.5	34 0	−1.3	−1.4
7 30	6.8	7.0	12 30	4.1	4.3	36 0	1.2	1.3
7 40	6.7	6.8	13 0	4.0	4.1	38 0	1.1	1.2
7 50	6.5	6.7	13 30	3.8	4.0	40 0	1.0	1.2
8 0	6.4	6.6	14 0	3.7	3.8	45 0	0.9	1.0
8 10	−6.3	−6.4	15 0	−3.4	−3.6	50 0	−0.7	−0.8
8 20	6.2	6.3	16 0	3.2	3.3	55 0	0.6	0.7
8 30	6.1	6.2	17 0	3.0	3.1	60 0	0.5	0.6
8 40	5.9	6.1	18 0	2.8	3.0	65 0	0.4	0.5
8 50	5.8	6.0	19 0	2.7	2.8	70 0	0.3	0.4
9 0	−5.7	−5.9	20 0	−2.5	−2.6	75 0	−0.2	−0.3
9 20	5.5	5.7	21 0	2.4	2.5	80 0	0.1	0.2
9 40	5.3	5.5	22 0	2.3	2.4	85 0	−0.1	−0.1
10 0	−5.2	−5.3	24 0	−2.0	−2.2	90 0	0.0	0.0

TABLE F

BUBBLE SEXTANT CORRECTION TO OBSERVED ALTITUDE OF MOON

FOR REFRACTION AND PARALLAX

Obs. Altitude	Horizontal Parallax								Obs. Altitude	Horizontal Parallax							
	54′	55′	56′	57′	58′	59′	60′	61′		54′	55′	56′	57′	58′	59′	60′	61′
°	′	′	′	′	′	′	′	′	°	′	′	′	′	′	′	′	′
5.5	+44.6	+45.6	+46.6	+47.6	+48.6	+49.6	+50.6	+51.6	46	+36.6	+37.3	+38.0	+38.7	+39.4	+40.1	+40.8	+41.5
6.0	45.2	46.2	47.2	48.2	49.2	50.2	51.2	52.2	47	35.9	36.6	37.3	38.0	38.7	39.4	40.0	40.7
6.5	45.8	46.8	47.8	48.8	49.7	50.7	51.7	52.7	48	35.3	35.9	36.6	37.3	37.9	38.6	39.3	40.0
7.0	46.2	47.2	48.2	49.2	50.2	51.2	52.2	53.2	49	34.6	35.2	35.9	36.6	37.2	37.9	38.5	39.2
7.5	46.6	47.6	48.6	49.6	50.6	51.6	52.6	53.6	50	33.9	34.5	35.2	35.8	36.5	37.1	37.8	38.4
8.0	+46.9	+47.9	+48.9	+49.9	+50.9	+51.9	+52.9	+53.9	51	+33.2	+33.8	+34.5	+35.1	+35.7	+36.4	+37.0	+37.6
8.5	47.2	48.2	49.2	50.2	51.2	52.2	53.2	54.2	52	32.5	33.1	33.7	34.3	35.0	35.6	36.2	36.8
9.0	47.5	48.5	49.4	50.4	51.4	52.4	53.4	54.4	53	31.8	32.4	33.0	33.6	34.2	34.8	35.4	36.0
9.5	47.7	48.7	49.7	50.6	51.6	52.6	53.6	54.6	54	31.1	31.6	32.2	32.8	33.4	34.0	34.6	35.2
10.0	47.9	48.9	49.9	50.8	51.8	52.8	53.8	54.8	55	30.3	30.9	31.5	32.0	32.6	33.2	33.8	34.3
11	+48.2	+49.2	+50.1	+51.1	+52.1	+53.1	+54.1	+55.1	56	+29.6	+30.1	+30.7	+31.2	+31.8	+32.4	+32.9	+33.5
12	48.4	49.4	50.3	51.3	52.3	53.3	54.2	55.2	57	28.8	29.3	29.9	30.4	31.0	31.5	32.1	32.6
13	48.5	49.5	50.4	51.4	52.4	53.4	54.4	55.3	58	28.0	28.5	29.1	29.6	30.2	30.7	31.2	31.7
14	48.6	49.6	50.5	51.5	52.5	53.4	54.4	55.4	59	27.2	27.7	28.3	28.8	29.3	29.8	30.3	30.8
15	48.6	49.6	50.5	51.5	52.5	53.4	54.4	55.4	60	26.4	26.9	27.5	28.0	28.5	29.0	29.5	29.9
16	+48.6	+49.5	+50.5	+51.5	+52.4	+53.4	+54.3	+55.3	61	+25.6	+26.1	+26.6	+27.1	+27.6	+28.1	+28.6	+29.0
17	48.5	49.5	50.4	51.4	52.3	53.3	54.3	55.2	62	24.8	25.3	25.8	26.3	26.7	27.2	27.7	28.1
18	48.4	49.4	50.3	51.3	52.2	53.2	54.1	55.1	63	24.0	24.5	24.9	25.4	25.9	26.3	26.8	27.2
19	48.3	49.2	50.2	51.1	52.1	53.0	54.0	54.9	64	23.2	23.7	24.1	24.5	25.0	25.4	25.8	26.3
20	48.1	49.0	50.0	50.9	51.9	52.8	53.8	54.7	65	22.4	22.8	23.2	23.7	24.1	24.5	24.9	25.4

21	+47.9	+48.8	+49.8	+50.7	+51.7	+52.6	+53.5	+54.5	66	+21.5	+22.0	+22.4	+22.8	+23.2	+23.6	+24.0	+24.4
22	47.7	48.6	49.6	50.5	51.4	52.3	53.3	54.2	67	20.7	21.1	21.5	21.9	22.3	22.7	23.0	23.4
23	47.5	48.4	49.3	50.2	51.1	52.0	53.0	53.9	68	19.8	20.2	20.6	21.0	21.4	21.7	22.1	22.5
24	47.2	48.1	49.0	49.9	50.8	51.7	52.7	53.6	69	19.0	19.4	19.7	20.1	20.4	20.8	21.1	21.5
25	46.9	47.8	48.7	49.6	50.5	51.4	52.3	53.2	70	18.1	18.5	18.8	19.2	19.5	19.8	20.2	20.5
26	+46.6	+47.5	+48.4	+49.3	+50.2	+51.1	+52.0	+52.9	71	+17.3	+17.6	+17.9	+18.2	+18.6	+18.9	+19.2	+19.5
27	46.2	47.1	48.0	48.9	49.8	50.7	51.6	52.5	72	16.4	16.7	17.0	17.3	17.6	17.9	18.2	18.5
28	45.9	46.8	47.6	48.5	49.4	50.3	51.2	52.1	73	15.5	15.8	16.1	16.4	16.7	17.0	17.3	17.5
29	45.5	46.4	47.2	48.1	49.0	49.9	50.8	51.6	74	14.6	14.9	15.2	15.4	15.7	16.0	16.3	16.5
30	45.1	46.0	46.8	47.7	48.6	49.4	50.3	51.2	75	13.7	14.0	14.2	14.5	14.8	15.0	15.3	15.5
31	+44.7	+45.6	+46.4	+47.3	+48.1	+49.0	+49.8	+50.7	76	+12.8	+13.1	+13.3	+13.5	+13.8	+14.0	+14.3	+14.5
32	44.3	45.1	46.0	46.8	47.7	48.5	49.4	50.2	77	11.9	12.2	12.4	12.6	12.8	13.1	13.3	13.5
33	43.8	44.7	45.5	46.3	47.2	48.0	48.8	49.7	78	11.0	11.2	11.4	11.6	11.9	12.1	12.3	12.5
34	43.4	44.2	45.0	45.8	46.7	47.5	48.3	49.2	79	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5
35	42.9	43.7	44.5	45.3	46.2	47.0	47.8	48.6	80	9.2	9.4	9.6	9.7	9.9	10.1	10.2	10.4
36	+42.4	+43.2	+44.0	+44.8	+45.6	+46.4	+47.2	+48.0	81	+ 8.3	+ 8.5	+ 8.6	+ 8.8	+ 8.9	+ 9.1	+ 9.2	+ 9.4
37	41.9	42.7	43.5	44.3	45.1	45.9	46.6	47.4	82	7.4	7.5	7.6	7.8	8.0	8.1	8.2	8.4
38	41.3	42.1	42.9	43.7	44.5	45.3	46.0	46.8	83	6.5	6.6	6.7	6.8	7.0	7.1	7.2	7.3
39	40.8	41.6	42.3	43.1	43.9	44.7	45.4	46.2	84	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3
40	40.2	41.0	41.8	42.5	43.3	44.1	44.8	45.6	85	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.2
41	+39.7	+40.4	+41.2	+41.9	+42.7	+43.4	+44.2	+44.9	86	+ 3.7	+ 3.8	+ 3.8	+ 3.9	+ 4.0	+ 4.0	+ 4.1	+ 4.2
42	39.1	39.8	40.6	41.3	42.0	42.8	43.5	44.3	87	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.1
43	38.5	39.2	39.9	40.7	41.4	42.1	42.9	43.6	88	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1
44	37.9	38.6	39.3	40.0	40.7	41.5	42.2	42.9	89	+ 0.9	+ 0.9	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0	+ 1.0
45	+37.2	+37.9	+38.6	+39.4	+40.1	+40.8	+41.5	+42.2	90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

GREENWICH HOUR ANGLE OF POLARIS, 1939

FOR 0h GREENWICH CIVIL TIME

	° ′		° ′		° ′		° ′		° ′		° ′
Jan. 1	74 1.4	Mar. 1	132 27.1	May 1	192 38.5	July 1	252 32.0	Sept. 1	313 20.4	Nov. 1	13 20.2
2	75 0.8	2	133 26.5	2	193 37.5	2	253 30.9	2	314 19.3	2	14 19.4
3	76 0.2	3	134 25.8	3	194 36.5	3	254 29.7	3	315 18.2	3	15 18.5
4	76 59.7	4	135 25.2	4	195 35.6	4	255 28.5	4	316 17.1	4	16 17.7
5	77 59.1	5	136 24.5	5	196 34.6	5	256 27.4	5	317 16.0	5	17 16.9
6	78 58.5	6	137 23.9	6	197 33.6	6	257 26.2	6	318 15.0	6	18 16.0
7	79 57.9	7	138 23.2	7	198 32.6	7	258 25.0	7	319 13.9	7	19 15.2
8	80 57.3	8	139 22.6	8	199 31.6	8	259 23.9	8	320 12.8	8	20 14.4
9	81 56.8	9	140 21.9	9	200 30.6	9	260 22.7	9	321 11.7	9	21 13.6
10	82 56.2	10	141 21.2	10	201 29.6	10	261 21.5	10	322 10.6	10	22 12.8
11	83 55.6	11	142 20.5	11	202 28.6	11	262 20.3	11	323 9.5	11	23 12.0
12	84 55.1	12	143 19.8	12	203 27.5	12	263 19.2	12	324 8.5	12	24 11.2
13	85 54.5	13	144 19.1	13	204 26.5	13	264 18.0	13	325 7.4	13	25 10.4
14	86 53.9	14	145 18.4	14	205 25.5	14	265 16.8	14	326 6.3	14	26 9.6
15	87 53.4	15	146 17.7	15	206 24.5	15	266 15.6	15	327 5.3	15	27 8.8
16	88 52.8	16	147 17.0	16	207 23.4	16	267 14.4	16	328 4.2	16	28 8.1
17	89 52.2	17	148 16.3	17	208 22.4	17	268 13.3	17	329 3.2	17	29 7.3
18	90 51.7	18	149 15.6	18	209 21.3	18	269 12.1	18	330 2.1	18	30 6.5
19	91 51.1	19	150 14.9	19	210 20.3	19	270 10.9	19	331 1.1	19	31 5.8
20	92 50.5	20	151 14.1	20	211 19.2	20	271 9.8	20	332 0.0	20	32 5.0
21	93 50.0	21	152 13.4	21	212 18.2	21	272 8.6	21	332 59.0	21	33 4.3
22	94 49.4	22	153 12.7	22	213 17.1	22	273 7.4	22	333 58.0	22	34 3.5
23	95 48.9	23	154 11.9	23	214 16.0	23	274 6.2	23	334 57.0	23	35 2.8
24	96 48.3	24	155 11.2	24	215 15.0	24	275 5.0	24	335 55.9	24	36 2.1
25	97 47.8	25	156 10.4	25	216 13.9	25	276 3.9	25	336 54.9	25	37 1.3
26	98 47.2	26	157 9.6	26	217 12.8	26	277 2.7	26	337 53.9	26	38 0.6
27	99 46.6	27	158 8.9	27	218 11.7	27	278 1.5	27	338 52.9	27	38 59.8
28	100 46.1	28	159 8.1	28	219 10.6	28	279 0.4	28	339 51.9	28	39 59.1
29	101 45.5	29	160 7.3	29	220 9.5	29	279 59.2	29	340 50.9	29	40 58.4
30	102 44.9	30	161 6.6	30	221 8.5	30	280 58.0	30	341 49.9	30	41 57.7

31	103 44.4	31	162 5.8	31	222 7.4	31	281 56.9	Oct. 1	342 48.9	Dec. 1	42 57.0
Feb. 1	104 43.8	Apr. 1	163 5.0	June 1	223 6.3	Aug. 1	282 55.7	2	343 47.9	2	43 56.3
2	105 43.2	2	164 4.2	2	224 5.2	2	283 54.5	3	344 46.9	3	44 55.6
3	106 42.7	3	165 3.4	3	225 4.0	3	284 53.4	4	345 45.9	4	45 54.9
4	107 42.1	4	166 2.6	4	226 2.9	4	285 52.2	5	346 44.9	5	46 54.2
5	108 41.5	5	167 1.7	5	227 1.8	5	286 51.0	6	347 44.0	6	47 53.6
6	109 41.0	6	168 0.9	6	228 0.7	6	287 49.9	7	348 43.0	7	48 52.9
7	110 40.4	7	169 0.0	7	228 59.6	7	288 48.7	8	349 42.0	8	49 52.2
8	111 39.8	8	169 59.2	8	229 58.5	8	289 47.6	9	350 41.0	9	50 51.5
9	112 39.2	9	170 58.4	9	230 57.3	9	290 46.4	10	351 40.1	10	51 50.9
10	113 38.7	10	171 57.6	10	231 56.2	10	291 45.3	11	352 39.1	11	52 50.2
11	114 38.1	11	172 56.7	11	232 55.1	11	292 44.1	12	353 38.2	12	53 49.6
12	115 37.5	12	173 55.9	12	233 54.0	12	293 43.0	13	354 37.2	13	54 48.9
13	116 36.9	13	174 55.0	13	234 52.8	13	294 41.8	14	355 36.3	14	55 48.3
14	117 36.3	14	175 54.1	14	235 51.7	14	295 40.7	15	356 35.4	15	56 47.6
15	118 35.7	15	176 53.2	15	236 50.5	15	296 39.5	16	357 34.4	16	57 47.0
16	119 35.1	16	177 52.4	16	237 49.4	16	297 38.4	17	358 33.5	17	58 46.4
17	120 34.5	17	178 51.5	17	238 48.3	17	298 37.2	18	359 32.6	18	59 45.7
18	121 33.9	18	179 50.6	18	239 47.1	18	299 36.1	19	0 31.7	19	60 45.1
19	122 33.3	19	180 49.7	19	240 46.0	19	300 35.0	20	1 30.8	20	61 44.5
20	123 32.7	20	181 48.8	20	241 44.8	20	301 33.8	21	2 29.9	21	62 43.9
21	124 32.1	21	182 47.9	21	242 43.7	21	302 32.7	22	3 29.0	22	63 43.2
22	125 31.5	22	183 47.0	22	243 42.5	22	303 31.6	23	4 28.1	23	64 42.6
23	126 30.9	23	184 46.0	23	244 41.3	23	304 30.4	24	5 27.2	24	65 42.0
24	127 30.3	24	185 45.1	24	245 40.2	24	305 29.3	25	6 26.3	25	66 41.4
25	128 29.7	25	186 44.2	25	246 39.0	25	306 28.2	26	7 25.4	26	67 40.8
26	129 29.0	26	187 43.2	26	247 37.9	26	307 27.1	27	8 24.5	27	68 40.2
27	130 28.4	27	188 42.3	27	248 36.7	27	308 26.0	28	9 23.7	28	69 39.6
28	131 27.8	28	189 41.3	28	249 35.5	28	309 24.8	29	10 22.8	29	70 39.0
29	132 27.1	29	190 40.4	29	250 34.4	29	310 23.7	30	11 22.0	30	71 38.4
30	133 26.5	30	191 39.4	30	251 33.2	30	311 22.6	31	12 21.1	31	72 37.8
31	134 25.8	31	192 38.5	31	252 32.0	31	312 21.5	32	13 20.2	32	73 37.2

TABLE III

FOR FINDING LATITUDE BY AN OBSERVED ALTITUDE OF POLARIS, 1939

HOUR ANGLE ARGUMENT

Correction for Local Hour Angle to be Applied to True Altitude

L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.	L.H.A.	Corr.
°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′
0	−1 1.3	60	−0 30.2	120	+0 31.1	180	+1 1.3	240	+0 31.1	300	−0 30.2
1	1 1.3	61	0 29.3	121	0 32.0	181	1 1.3	241	0 30.2	301	0 31.1
2	1 1.3	62	0 28.4	122	0 32.9	182	1 1.3	242	0 29.2	302	0 32.1
3	1 1.2	63	0 27.4	123	0 33.8	183	1 1.2	243	0 28.3	303	0 33.0
4	1 1.2	64	0 26.4	124	0 34.7	184	1 1.2	244	0 27.3	304	0 33.9
5	−1 1.1	65	−0 25.5	125	+0 35.6	185	+1 1.1	245	+0 26.4	305	−0 34.8
6	1 1.0	66	0 24.5	126	0 36.4	186	1 1.0	246	0 25.4	306	0 35.7
7	1 0.9	67	0 23.5	127	0 37.3	187	1 0.9	247	0 24.4	307	0 36.6
8	1 0.7	68	0 22.5	128	0 38.1	188	1 0.8	248	0 23.5	308	0 37.4
9	1 0.6	69	0 21.5	129	0 38.9	189	1 0.6	249	0 22.5	309	0 38.3
10	−1 0.4	70	−0 20.5	130	+0 39.7	190	+1 0.4	250	+0 21.5	310	−0 39.1
11	1 0.2	71	0 19.5	131	0 40.5	191	1 0.2	251	0 20.5	311	0 39.9
12	1 0.0	72	0 18.5	132	0 41.3	192	1 0.0	252	0 19.5	312	0 40.7
13	0 59.7	73	0 17.4	133	0 42.1	193	0 59.8	253	0 18.4	313	0 41.5
14	0 59.5	74	0 16.4	134	0 42.9	194	0 59.5	254	0 17.4	314	0 42.3
15	−0 59.2	75	−0 15.4	135	+0 43.7	195	+0 59.3	255	+0 16.4	315	−0 43.1
16	0 58.9	76	0 14.3	136	0 44.4	196	0 59.0	256	0 15.4	316	0 43.9
17	0 58.6	77	0 13.3	137	0 45.1	197	0 58.7	257	0 14.3	317	0 44.6
18	0 58.3	78	0 12.2	138	0 45.8	198	0 58.4	258	0 13.3	318	0 45.3
19	0 57.9	79	0 11.2	139	0 46.5	199	0 58.1	259	0 12.2	319	0 46.1
20	−0 57.6	80	−0 10.1	140	+0 47.2	200	+0 57.7	260	+0 11.1	320	−0 46.8
21	0 57.2	81	0 9.1	141	0 47.9	201	0 57.3	261	0 10.1	321	0 47.5
22	0 56.8	82	0 8.0	142	0 48.5	202	0 56.9	262	0 9.1	322	0 48.1
23	0 56.4	83	0 7.0	143	0 49.2	203	0 56.5	263	0 8.0	323	0 48.8
24	0 55.9	84	0 5.9	144	0 49.8	204	0 56.1	264	0 7.0	324	0 49.4

25	−0 55.5	85	−0 4.8	145	+0 50.4	205	+0 55.7	265	+0 5.9	325	−0 50.0
26	0 55.0	86	0 3.7	146	0 51.0	206	0 55.2	266	0 4.8	326	0 50.7
27	0 54.5	87	0 2.7	147	0 51.6	207	0 54.8	267	0 3.8	327	0 51.3
28	0 54.0	88	0 1.6	148	0 52.2	208	0 54.3	268	0 2.7	328	0 51.9
29	0 53.5	89	−0 0.5	149	0 52.7	209	0 53.8	269	0 1.6	329	0 52.5
30	−0 53.0	90	+0 0.6	150	+0 53.3	210	+0 53.3	270	+0 0.6	330	−0 53.0
31	0 52.5	91	0 1.6	151	0 53.8	211	0 52.7	271	−0 0.5	331	0 53.5
32	0 51.9	92	0 2.7	152	0 54.3	212	0 52.2	272	0 1.6	332	0 54.0
33	0 51.3	93	0 3.8	153	0 54.8	213	0 51.6	273	0 2.7	333	0 54.5
34	0 50.7	94	0 4.8	154	0 55.2	214	0 51.0	274	0 3.7	334	0 55.0
35	−0 50.0	95	+0 5.9	155	+0 55.7	215	+0 50.4	275	−0 4.8	335	−0 55.5
36	0 49.4	96	0 7.0	156	0 56.1	216	0 49.8	276	0 5.9	336	0 55.9
37	0 48.8	97	0 8.0	157	0 56.5	217	0 49.2	277	0 7.0	337	0 56.4
38	0 48.1	98	0 9.1	158	0 56.9	218	0 48.5	278	0 8.0	338	0 56.8
39	0 47.5	99	0 10.1	159	0 57.3	219	0 47.9	279	0 9.1	339	0 57.2
40	−0 46.8	100	+0 11.1	160	+0 57.7	220	+0 47.2	280	−0 10.1	340	−0 57.6
41	0 46.1	101	0 12.2	161	0 58.1	221	0 46.5	281	0 11.2	341	0 57.9
42	0 45.3	102	0 13.3	162	0 58.4	222	0 45.8	282	0 12.2	342	0 58.3
43	0 44.6	103	0 14.3	163	0 58.7	223	0 45.1	283	0 13.3	343	0 58.6
44	0 43.9	104	0 15.4	164	0 59.0	224	0 44.4	284	0 14.3	344	0 58.9
45	−0 43.1	105	+0 16.4	165	+0 59.3	225	+0 43.7	285	−0 15.4	345	−0 59.2
46	0 42.3	106	0 17.4	166	0 59.5	226	0 42.9	286	0 16.4	346	0 59.5
47	0 41.5	107	0 18.4	167	0 59.8	227	0 42.1	287	0 17.4	347	0 59.7
48	0 40.7	108	0 19.5	168	1 0.0	228	0 41.3	288	0 18.5	348	1 0.0
49	0 39.9	109	0 20.5	169	1 0.2	229	0 40.5	289	0 19.5	349	1 0.2
50	−0 39.1	110	+0 21.5	170	+1 0.4	230	+0 39.7	290	−0 20.5	350	−1 0.4
51	0 38.3	111	0 22.5	171	1 0.6	231	0 38.9	291	0 21.5	351	1 0.6
52	0 37.4	112	0 23.5	172	1 0.8	232	0 38.1	292	0 22.5	352	1 0.7
53	0 36.6	113	0 24.4	173	1 0.9	233	0 37.3	293	0 23.5	353	1 0.9
54	0 35.7	114	0 25.4	174	1 1.0	234	0 36.4	294	0 24.5	354	1 1.0
55	−0 34.8	115	+0 26.4	175	+1 1.1	235	+0 35.6	295	−0 25.5	355	−1 1.1
56	0 33.9	116	0 27.3	176	1 1.2	236	0 34.7	296	0 26.4	356	1 1.2
57	0 33.0	117	0 28.3	177	1 1.2	237	0 33.8	297	0 27.4	357	1 1.2
58	0 32.1	118	0 29.2	178	1 1.3	238	0 32.9	298	0 28.4	358	1 1.3
59	0 31.1	119	0 30.2	179	1 1.3	239	0 32.0	299	0 29.3	359	1 1.3
60	−0 30.2	120	+0 31.1	180	+1 1.3	240	+0 31.1	300	−0 30.2	360	−1 1.3

SUN, 1939

Day of Month	Sidereal Time of 0^h Civil Time at Greenwich (R. A. M. S.+12^h)					
	January	February	March	April	May	June
	h m s	h m s	h m s	h m s	h m s	h m s
1	6 38 59.4	8 41 12.7	10 31 36.2	12 33 49.3	14 32 5.9	16 34 19.1
2	6 42 56.0	8 45 9.3	10 35 32.8	12 37 45.9	14 36 2.5	16 38 15.7
3	6 46 52.6	8 49 5.8	10 39 29.3	12 41 42.4	14 39 59.0	16 42 12.3
4	6 50 49.1	8 53 2.4	10 43 25.9	12 45 39.0	14 43 55.6	16 46 8.8
5	6 54 45.7	8 56 58.9	10 47 22.4	12 49 35.5	14 47 52.1	16 50 5.4
6	6 58 42.3	9 0 55.5	10 51 19.0	12 53 32.1	14 51 48.7	16 54 1.9
7	7 2 38.8	9 4 52.1	10 55 15.5	12 57 28.6	14 55 45.3	16 57 58.5
8	7 6 35.4	9 8 48.6	10 59 12.1	13 1 25.2	14 59 41.8	17 1 55.0
9	7 10 31.9	9 12 45.2	11 3 8.6	13 5 21.8	15 3 38.4	17 5 51.6
10	7 14 28.5	9 16 41.7	11 7 5.2	13 9 18.3	15 7 34.9	17 9 48.2
11	7 18 25.0	9 20 38.3	11 11 1.7	13 13 14.9	15 11 31.5	17 13 44.7
12	7 22 21.6	9 24 34.8	11 14 58.3	13 17 11.4	15 15 28.0	17 17 41.3
13	7 26 18.1	9 28 31.4	11 18 54.9	13 21 8.0	15 19 24.6	17 21 37.8
14	7 30 14.7	9 32 27.9	11 22 51.4	13 25 4.5	15 23 21.1	17 25 34.4
15	7 34 11.3	9 36 24.5	11 26 48.0	13 29 1.1	15 27 17.7	17 29 30.9
16	7 38 7.8	9 40 21.0	11 30 44.5	13 32 57.6	15 31 14.2	17 33 27.5
17	7 42 4.4	9 44 17.6	11 34 41.1	13 36 54.2	15 35 10.8	17 37 24.0
18	7 46 0.9	9 48 14.2	11 38 37.6	13 40 50.7	15 39 7.3	17 41 20.6
19	7 49 57.5	9 52 10.7	11 42 34.2	13 44 47.3	15 43 3.9	17 45 17.2
20	7 53 54.1	9 56 7.3	11 46 30.7	13 48 43.8	15 47 0.5	17 49 13.7
21	7 57 50.6	10 0 3.8	11 50 27.3	13 52 40.4	15 50 57.0	17 53 10.3
22	8 1 47.2	10 4 0.3	11 54 23.8	13 56 36.9	15 54 53.6	17 57 6.8
23	8 5 43.7	10 7 56.9	11 58 20.4	14 0 33.5	15 58 50.1	18 1 3.4
24	8 9 40.3	10 11 53.4	12 2 16.9	14 4 30.0	16 2 46.7	18 5 0.0
25	8 13 36.8	10 15 50.0	12 6 13.5	14 8 26.6	16 6 43.3	18 8 56.5

26	8 17 33.4	10 19 46.6	12 10 10.0	14 12 23.2	16 10 39.8	18 12 53.1
27	8 21 29.9	10 23 43.1	12 14 6.6	14 16 19.7	16 14 36.4	18 16 49.6
28	8 25 26.5	10 27 39.7	12 18 3.1	14 20 16.3	16 18 32.9	18 20 46.2
29	8 29 23.0	10 31 36.2	12 21 59.7	14 24 12.8	16 22 29.5	18 24 42.7
30	8 33 19.6	10 35 32.8	12 25 56.2	14 28 9.4	16 26 26.0	18 28 39.3
31	8 37 16.2	10 39 29.3	12 29 52.8	14 32 5.9	16 30 22.6	18 32 35.8

CORRECTION FOR LONGITUDE FROM GREENWICH

(This correction table is equivalent to Table VI)

Longitude	0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h
m	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
0	0 0.0	0 9.9	0 19.7	0 29.6	0 39.4	0 49.3	0 59.1	1 9.0	1 18.9	1 28.7	1 38.6	1 48.4
5	0 0.8	0 10.7	0 20.5	0 30.4	0 40.2	0 50.1	1 0.0	1 9.8	1 19.7	1 29.5	1 39.4	1 49.2
10	0 1.6	0 11.5	0 21.4	0 31.2	0 41.1	0 50.9	1 0.8	1 10.6	1 20.5	1 30.4	1 40.2	1 50.1
15	0 2.5	0 12.3	0 22.2	0 32.0	0 41.9	0 51.7	1 1.6	1 11.5	1 21.3	1 31.2	1 41.0	1 50.9
20	0 3.3	0 13.1	0 23.0	0 32.9	0 42.7	0 52.6	1 2.4	1 12.3	1 22.1	1 32.0	1 41.8	1 51.7
25	0 4.1	0 14.0	0 23.8	0 33.7	0 43.5	0 53.4	1 3.2	1 13.1	1 23.0	1 32.8	1 42.7	1 52.5
30	0 4.9	0 14.8	0 24.6	0 34.5	0 44.4	0 54.2	1 4.1	1 13.9	1 23.8	1 33.6	1 43.5	1 53.3
35	0 5.8	0 15.6	0 25.5	0 35.3	0 45.2	0 55.0	1 4.9	1 14.7	1 24.6	1 34.5	1 44.3	1 54.2
40	0 6.6	0 16.4	0 26.3	0 36.1	0 46.0	0 55.9	1 5.7	1 15.6	1 25.4	1 35.3	1 45.1	1 55.0
45	0 7.4	0 17.2	0 27.1	0 37.0	0 46.8	0 56.7	1 6.5	1 16.4	1 26.2	1 36.1	1 46.0	1 55.8
50	0 8.2	0 18.1	0 27.9	0 37.8	0 47.6	0 57.5	1 7.4	1 17.2	1 27.1	1 36.9	1 46.8	1 56.6
55	0 9.0	0 18.9	0 28.7	0 38.6	0 48.5	0 58.3	1 8.2	1 18.0	1 27.9	1 37.7	1 47.6	1 57.5
60	0 9.9	0 19.7	0 29.6	0 39.4	0 49.3	0 59.1	1 9.0	1 18.9	1 28.7	1 38.6	1 48.4	1 58.3

P. P.	
m	s
1	0.2
2	0.3
3	0.5
4	0.7
5	0.8

NOTE.—The correction is to be added to Sidereal Time of 0^h Civil Time at Greenwich to obtain Sidereal Time of 0^h Civil Time at any longitude west of Greenwich; to be subtracted if the longitude is east of Greenwich.

MEAN PLACES OF ADDITIONAL STARS, 1939

FOR JANUARY $1^d.259$ GREENWICH CIVIL TIME

Name of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
γ Pegasi (*Algenib*)	2.9	0 10 5.5	+3.09	+14 50 41	+20.0
β Hydri	2.9	0 22 34.7	3.17	−77 35 52	20.3
α Phœnicis	2.4	0 23 16.4	2.97	−42 38 13	19.6
α Cassiop. (*Schedir*) (*var.*)	2.1–2.6	0 37 1.8	3.40	+56 12 12	19.8
γ Cassiopeiæ	2.2	0 53 0.5	3.61	+60 23 13	19.5
β Andromedæ (*Mirach*)	2.4	1 6 18.5	+3.36	+35 17 52	+19.1
β Arietis (*Sheratan*)	2.7	1 51 15.9	3.31	+20 30 38	17.6
α Hydri	3.0	1 56 50.9	1.80	−61 51 58	17.5
γ^1 Andromedæ (*Almach*)	2.3	2 0 8.7	3.68	+42 2 17	17.3
β Trianguli	3.1	2 5 54.3	3.57	+34 41 59	17.1
α Ceti (*Menkar*)	2.8	2 59 5.3	+3.14	+ 3 51 6	+14.2
γ Persei	3.1	3 0 21.8	4.34	+53 16 9	14.2
β Persei (*Algol*) (*var.*)	2.3–3.5	3 4 11.4	3.90	+40 43 20	13.9
η Tauri (*Alcyone*)	3.0	3 43 51.2	+3.56	+23 55 5	11.2
γ Hydri	3.2	3 48 9.6	−0.94	−74 25 35	11.0
ζ Persei	2.9	3 50 17.5	+3.77	+31 42 15	+10.7
ε Persei	3.0	3 53 45.2	4.02	+39 50 8	10.5
γ Eridani	3.2	3 55 10.9	2.80	−13 40 51	10.3
ι Aurigæ	2.9	4 53 1.0	3.91	+33 4 17	5.8
β Eridani	2.9	5 4 50.9	2.95	− 5 9 50	4.7
β Tauri (*El Nath*)	1.8	5 22 26.0	+3.79	+28 33 28	+ 3.1
δ Orionis	2.5	5 28 53.3	3.06	− 0 20 34	2.7
α Leporis (*Arneb*)	2.7	5 30 2.3	2.65	−17 51 52	2.6
ζ Tauri	3.0	5 33 59.8	3.59	+21 6 26	2.3
α Columbæ (*Phact*)	2.8	5 37 26.3	2.17	−34 6 19	2.0

ζ[1] Orionis	2.0	5 37 40.7	+3.03	− 1 58 23	+ 2.0
κ Orionis	2.2	5 44 51.7	2.85	− 9 41 24	1.3
β Aurigæ (*Menkalinan*)	2.1	5 55 3.2	4.40	+44 56 36	0.4
θ Aurigæ	2.7	5 55 33.6	4.09	+37 12 37	+ 0.3
β Canis Majoris	2.0	6 20 0.7	2.64	−17 55 28	− 1.7
γ Geminorum	1.9	6 34 11.2	+3.47	+16 27 11	− 3.0
τ Argus	2.8	6 48 25.2	1.49	−50 32 28	4.3
δ Canis Majoris	2.0	7 5 54.6	2.44	−26 17 42	5.7
π Argus	2.7	7 14 59.2	2.12	−36 59 12	6.4
η Canis Majoris	2.4	7 21 40.8	2.37	−29 10 59	7.0
β Canis Minoris	3.1	7 23 50.5	+3.25	+ 8 24 50	− 7.2
α Geminorum (*Castor*) *c.g.*	1.6	7 30 42.5	3.83	+32 1 26	7.8
ζ Argus	2.3	8 1 26.3	2.11	−39 49 49	10.1
ρ Argus	2.9	8 4 56.7	2.55	−24 7 38	10.3
γ Argus	1.9	8 7 39.1	1.85	−47 9 21	10.6
δ Argus (*mean*)	2.0	8 43 1.1	+1.66	−54 29 3	−13.2
ι Ursæ Majoris	3.1	8 55 2.4	4.11	+48 16 57	14.1
ι Argus	2.2	9 15 27.5	1.61	−59 1 7	15.1
κ Argus	2.6	9 20 13.4	1.86	−54 44 58	15.4
ε Leonis	3.1	9 42 23.5	3.41	+24 3 22	16.5
γ[1] Leonis	2.6	10 16 36.7	+3.31	+20 9 3	−18.2
μ Ursæ Majoris	3.2	10 18 42.1	3.58	+41 48 25	18.1
θ Argus	3.0	10 40 46.5	2.14	−64 4 28	18.8
μ Argus	2.9	10 44 8.4	2.58	−49 5 50	19.0
β Ursæ Majoris (*Merak*)	2.4	10 58 10.4	3.62	+56 42 36	19.3
ψ Ursæ Majoris	3.2	11 6 14.5	+3.37	+44 49 48	−19.5
δ Leonis	2.6	11 10 52.0	3.19	+20 51 30	19.7
γ Ursæ Majoris (*Phecda*)	2.5	11 50 37.8	3.16	+54 2 3	20.0
δ Centauri	2.9	12 5 11.3	3.11	−50 22 58	20.1
δ Crucis	3.1	12 11 53.6	+3.18	−58 24 34	−20.0

TABLE VIII

FOR CONVERSION OF ARC TO TIME

°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	'	m	s	"	s
0	0	0	60	4	0	120	8	0	180	12	0	240	16	0	300	20	0	0	0	0	0	0.00
1	0	4	61	4	4	121	8	4	181	12	4	241	16	4	301	20	4	1	0	4	1	0.07
2	0	8	62	4	8	122	8	8	182	12	8	242	16	8	302	20	8	2	0	8	2	0.13
3	0	12	63	4	12	123	8	12	183	12	12	243	16	12	303	20	12	3	0	12	3	0.20
4	0	16	64	4	16	124	8	16	184	12	16	244	16	16	304	20	16	4	0	16	4	0.27
5	0	20	65	4	20	125	8	20	185	12	20	245	16	20	305	20	20	5	0	20	5	0.33
6	0	24	66	4	24	126	8	24	186	12	24	246	16	24	306	20	24	6	0	24	6	0.40
7	0	28	67	4	28	127	8	28	187	12	28	247	16	28	307	20	28	7	0	28	7	0.47
8	0	32	68	4	32	128	8	32	188	12	32	248	16	32	308	20	32	8	0	32	8	0.53
9	0	36	69	4	36	129	8	36	189	12	36	249	16	36	309	20	36	9	0	36	9	0.60
10	0	40	70	4	40	130	8	40	190	12	40	250	16	40	310	20	40	10	0	40	10	0.67
11	0	44	71	4	44	131	8	44	191	12	44	251	16	44	311	20	44	11	0	44	11	0.73
12	0	48	72	4	48	132	8	48	192	12	48	252	16	48	312	20	48	12	0	48	12	0.80
13	0	52	73	4	52	133	8	52	193	12	52	253	16	52	313	20	52	13	0	52	13	0.87
14	0	56	74	4	56	134	8	56	194	12	56	254	16	56	314	20	56	14	0	56	14	0.93
15	1	0	75	5	0	135	9	0	195	13	0	255	17	0	315	21	0	15	1	0	15	1.00
16	1	4	76	5	4	136	9	4	196	13	4	256	17	4	316	21	4	16	1	4	16	1.07
17	1	8	77	5	8	137	9	8	197	13	8	257	17	8	317	21	8	17	1	8	17	1.13
18	1	12	78	5	12	138	9	12	198	13	12	258	17	12	318	21	12	18	1	12	18	1.20
19	1	16	79	5	16	139	9	16	199	13	16	259	17	16	319	21	16	19	1	16	19	1.27
20	1	20	80	5	20	140	9	20	200	13	20	260	17	20	320	21	20	20	1	20	20	1.33
21	1	24	81	5	24	141	9	24	201	13	24	261	17	24	321	21	24	21	1	24	21	1.40
22	1	28	82	5	28	142	9	28	202	13	28	262	17	28	322	21	28	22	1	28	22	1.47
23	1	32	83	5	32	143	9	32	203	13	32	263	17	32	323	21	32	23	1	32	23	1.53
24	1	36	84	5	36	144	9	36	204	13	36	264	17	36	324	21	36	24	1	36	24	1.60
25	1	40	85	5	40	145	9	40	205	13	40	265	17	40	325	21	40	25	1	40	25	1.67
26	1	44	86	5	44	146	9	44	206	13	44	266	17	44	326	21	44	26	1	44	26	1.73
27	1	48	87	5	48	147	9	48	207	13	48	267	17	48	327	21	48	27	1	48	27	1.80
28	1	52	88	5	52	148	9	52	208	13	52	268	17	52	328	21	52	28	1	52	28	1.87
29	1	56	89	5	56	149	9	56	209	13	56	269	17	56	329	21	56	29	1	56	29	1.93

30	2 0	90	6 0	150	10 0	210	14 0	270	18 0	330	22 0	30	2 0	30	2.00
31	2 4	91	6 4	151	10 4	211	14 4	271	18 4	331	22 4	31	2 4	31	2.07
32	2 8	92	6 8	152	10 8	212	14 8	272	18 8	332	22 8	32	2 8	32	2.13
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12	33	2 12	33	2.20
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16	34	2 16	34	2.27
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20	35	2 20	35	2.33
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24	36	2 24	36	2.40
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28	37	2 28	37	2.47
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32	38	2 32	38	2.53
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36	39	2 36	39	2.60
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40	40	2 40	40	2.67
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44	41	2 44	41	2.73
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48	42	2 48	42	2.80
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52	43	2 52	43	2.87
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56	44	2 56	44	2.93
45	3 0	105	7 0	165	11 0	225	15 0	285	19 0	345	23 0	45	3 0	45	3.00
46	3 4	106	7 4	166	11 4	226	15 4	286	19 4	346	23 4	46	3 4	46	3.07
47	3 8	107	7 8	167	11 8	227	15 8	287	19 8	347	23 8	47	3 8	47	3.13
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12	48	3 12	48	3.20
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16	49	3 16	49	3.27
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20	50	3 20	50	3.33
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24	51	3 24	51	3.40
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28	52	3 28	52	3.47
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32	53	3 32	53	3.53
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36	54	3 36	54	3.60
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40	55	3 40	55	3.67
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44	56	3 44	56	3.73
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48	57	3 48	57	3.80
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52	58	3 52	58	3.87
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56	59	3 56	59	3.93
60	4 0	120	8 0	180	12 0	240	16 0	300	20 0	360	24 0	60	4 0	60	4.00

CHAPTER VI

AIRWAYS SYSTEM OF THE UNITED STATES

The civil airways of the United States may be said to resemble a vast network of highways in which each different altitude level constitutes another whole layer of highways. As in highways, certain main airways are designated as through ones, and where congested airways cross, the traffic problem is handled just as on a modern highway, by an overhead crossing. Also, in the air, radio beams correspond to the white line on the highway so that aircraft may maintain a proper position to the right of the airway. This keeping to the right when flying a civil airway is one of the few traffic rules that apply at all times and yet it is one that is most frequently violated.

A civil airway is defined as an air route designated by the Administrator of the Civil Aeronautics Authority. It is 20 miles in width, and takes in all the airspace located vertically above the route. Each civil airway also includes the terminal and intermediate airports, emergency landing fields, and all other air navigation facilities located within the said area.

These airways are designated, in their order of precedence, as Green, Amber, Red, and Blue.

The Green airways are the main east-west transcontinental routes, Number One being the northernmost.

The Amber airways are the main north-south routes, Number One being the westernmost.

The Red airways are the short feeder lines in general running east and west. The Blue airways are the short feeder lines in general, running north and south.

Air navigation radio aids consisting of radio ranges and various types of markers are located along the airways. These radio aids enable a plane to determine its position regardless of weather conditions and further serve as a means for controlling movements of aircraft in flight.

Where the traffic is most congested on the airways the Civil Aeronautics Authority has set up traffic control centers to properly supervise all traffic within their areas. In the control of traffic, an airway traffic control center acts as a coordinating agency arranging the flow of traffic through its area in order to maintain an orderly

sequence of arrivals and departures, and to prevent the hazardous situation which may develop due to the close proximity of one aircraft to another.

Also within the Airways certain airports have been designated as control airports. These exercise control, through an airport control tower, over all traffic within a radius of 3 miles of the airport, to insure the safety of aircraft landing and departing therefrom. Where this radius does not take in the radio range station, the area of a control airport extends along a three-mile strip from the airport to the range station. The control airports that lie within an area served by an airway traffic control center do not function in the control of traffic until "Airways" has cleared the plane to the "Tower." Thus the proper safety of traffic within an airway control area is obtained by a close cooperation between "airways" and various control towers in the control area.

At certain points where two airways intersect outside an airway traffic control area there have been designated control zones of intersection which embrace an area having a radius of 25 miles from the center of the intersection. A control zone of intersection is served by the nearest Civil Aeronautics Authority communications station equipped with voice facilities. It should be noted that only airway traffic control centers are authorized to approve flight plans. Communications stations outside of airway traffic control areas function primarily in an informative advisory capacity.

In providing for the control of air traffic in the interest of safety, the United States Civil Aeronautics Authority has recognized the fact that there are two general weather conditions which determine the amount of ground control required for the purpose of minimizing the hazards of collision between aircraft in flight.

The first of these general conditions is when the pilot of an aircraft has sufficient visibility in all directions to permit him to see other aircraft in sufficient time to maneuver his own aircraft so as to avoid collision with other aircraft. A flight through this condition is commonly known as a flight under Contact Flight Rules.

The second of these general conditions is when the visibility is not good enough to permit "Contact Flight Rules" to apply and the pilot of an aircraft cannot readily see another aircraft because of haze, smoke, snow, rain, or other obstructions to his vision. Flight through this condition is known as flight under Instrument Flight Rules.

The Civil Aeronautics Authority issues flight rules for aircraft, regulations for their control along the airways, and instructions for their communications with traffic control centers. Pilots must familiarize themselves with these rules, regulations, and instructions before taking-off any aircraft.

CHAPTER VII

METEOROLOGY

INTRODUCTION

It would be highly desirable for every aviator to have a thorough knowledge of meteorology that he might always know what to expect from the various weather conditions encountered on his several missions.

That being a lifetime work in itself, it is the purpose of this chapter to touch (all too briefly) on some of the more important aspects from the aviator's point of view. It is hoped that he may obtain a general idea of the basic fundamentals of the weather processes, an understanding of the phenomena which are hazardous to aircraft, and some ability to interpret the weather information he observes or obtains.

Meteorology is the study of atmospheric phenomena, and embraces all the special branches. One of these is aerology, which, strictly speaking, is the study of the upper air. However, the term will be used in its broader sense which includes surface phenomena.

GLOSSARY OF TERMS

Adiabatic.—Changes in the pressure and density of a substance when no heat is communicated to or withdrawn from it.

Advection.—The process of transfer by horizontal motion.

Air mass—An extensive body of air approximately homogeneous horizontally.

Altimeter.—An aneroid barometer graduated to show height instead of pressure.

Anomaly.—The departure of a meterological element from its normal value.

Azimuth.—The horizontal angular deviation of an object from the true north and south line.

Ballistics.—The science of gunnery.

Bar.—The unit of atmospheric pressure of, or being equal to, the pressure of one million dynes per square centimeter.

Barograph.—A self-recording barometer.

Barometer.—An instrument for determining the pressure of the atmosphere.

Calibration.—The process of ascertaining the corrections to be applied to the indicated readings of an instrument in order to obtain true readings.

Cold front.—A front between two air masses where the advancing air is *colder* than that being displaced.

Condensation.—The process of formation of a liquid from its vapor.

Convergence.—A condition wherein more air flows into an area than flows out of it.

Convection.—In convection, heat is carried from one place to another by bodily transfer of the matter containing it. In general, if a part of a fluid is warmed, its volume is increased and the weight per unit of volume is less than before. The warmed part therefore rises and its place is taken by a fresh fluid which is warmed in turn; conversely, if it is cooled, it sinks.

Divergence.—The opposite of convergence.

Doldrums.—The equatorial oceanic regions of calms and light variable winds in which occur occasional heavy rains, thunderstorms, and squalls.

Dynamic cooling.—The falling of temperature produced by expansion due to diminished pressure.

Equinox.—The time of the year when the astronomical day and night are equal.

Front.—A boundary or zone of transition between air masses of different characteristics.

Gradient.—Adopted in meteorology to indicate the change in certain elements per unit horizontal distance.

Gradient wind.—The flow of air which is necessary to balance the pressure gradient.

Gravity.—The attraction between earth and material bodies.

Gust.—Comparatively rapid fluctuations in the strength of the wind.

Hydrometeor.—A generic term for weather phenomena such as rain, clouds, fog, etc.

Inversion.—An abbreviation for "inversion of temperature lapse rate"—an increase of temperature with height.

Isobar.—Lines drawn through points of equal pressure.

Isothermal.—Of equal temperature.

Lapse rate.—Refers to the fall of temperature with increased altitude.

Pitot tube.—An instrument for determining the velocity of a stream of fluid by measuring the increase of pressure above the undisturbed pressure in an open tube facing the stream.

Squall.—A strong wind that rises suddenly, lasts for some minutes. and dies comparatively suddenly away.

Subsidence.—The word used to denote the slow downward motion of the air over a large area which accompanies the divergence in the horizontal motion of the lower layers of the atmosphere.

Theodolite.—An instrument consisting of a telescope mounted to permit rotation in altitude and azimuth and fitted with divided circles to permit those coordinates to be read.

Thermodynamics.—That part of the science of heat which deals with the transformation of heat into other forms of energy and vice versa.

Warm front.—A front between two air masses where the advancing air is *warmer* than that being displaced.

Zenith.—The word is now commonly used as denoting a more or less extensive stretch of sky immediately overhead.

COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

As we know, the earth is enveloped by a mixture of gases and water vapor which are held adjacent to it by the force of gravity. Observation and spectrum analysis of auroras indicate that the depth of this atmospheric envelope is at least 200 miles.

Investigation of the lower portion of the atmosphere with the aid of airplanes, kites, manned balloons, and sounding balloons has furnished reliable information regarding its vertical structure. Analysis of samples show that it is composed approximately of 78 percent nitrogen, 21 percent oxygen, and a minor percentage of inert gases such as helium, xenon, and crypton, plus a certain amount of water vapor. The water vapor content is variable but in the lower several thousand feet will average about 1.2 percent. There is little known of the upper portion of the atmosphere but it is assumed that the lighter gases predominate.

In studying the vertical structure of the atmosphere one is introduced to the terms *troposphere*, *stratosphere*, and *tropopause*. They are used primarily to describe the main horizontal layers of the atmosphere as regards its vertical temperature distribution. The *troposphere* is that layer adjacent to the earth's surface wherein there is normally found a fall of temperature with increased altitude. The *stratosphere* is that portion of the atmosphere above the troposphere where there is no temperature fall with increased altitude, but in fact a slight rise. The *tropopause* is the layer or surface of demarkation between the troposphere and the stratosphere. The altitude of the tropopause is variable but generally closer to the earth's surface over polar regions (about 9 kilometers) than over equatorial regions (about 15 kilometers). Figure 93 is a vertical cross-section of the tropopause and the average vertical temperature distribution. Intersection

of the isothermal (equal temperature) surfaces with the plane of the meridian is shown for every 10° C.

The explanation of why the stratosphere exists is rather involved. For the purpose of this course it is sufficient to state that it is the

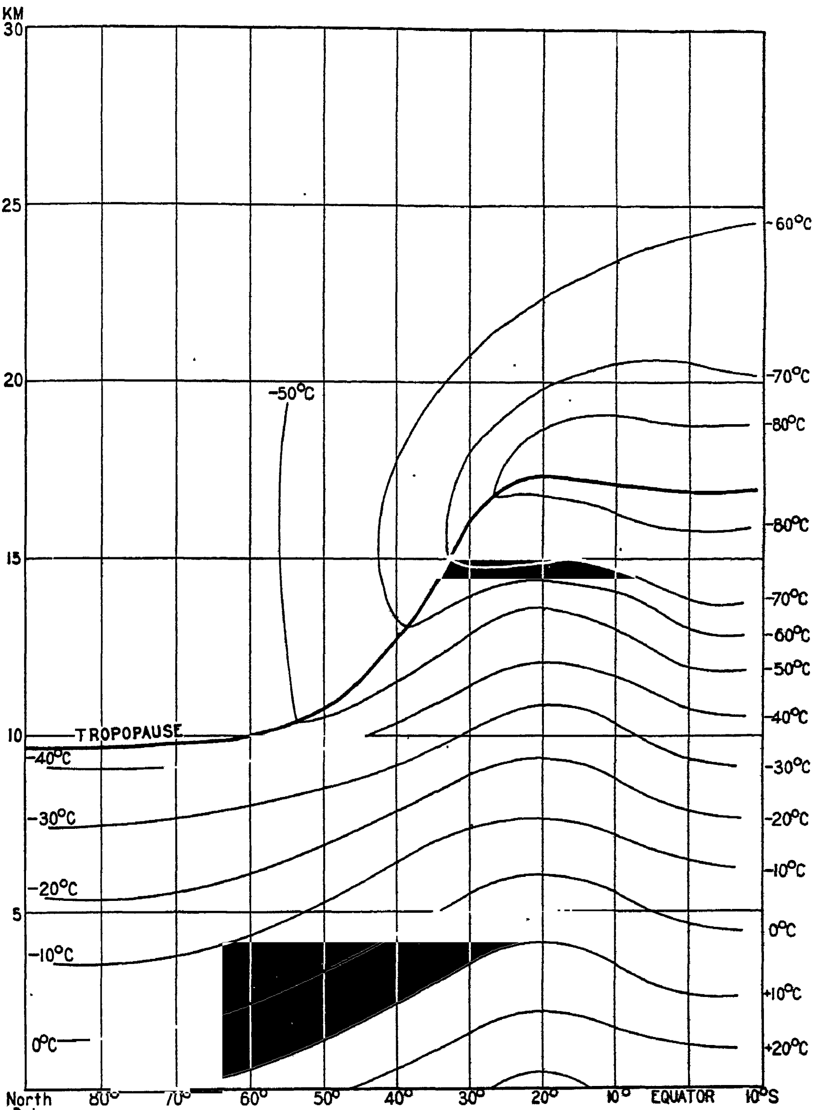

FIGURE 93.—Meridianal cross section showing vertical temperature distribution.

region in the atmosphere where temperature equilibrium exists between incoming solar radiation and the outgoing reradiation from the surface of the earth.

WEATHER ELEMENTS

In order to understand the dynamical processes which occur in the atmosphere—it is necessary that one know the physical laws of gases and have some knowledge of the principles of thermodynamics.

In studying the weather, the meteorologist makes use of observations of pressure, temperature, humidity, wind force and direction, and the state of weather at and above certain selected stations.

As has been stated, air is a mixture of gases and water vapor and, further, except for the variable amount of water vapor and solid impurities, the mixture is uniform in the troposphere. Dry air may thus be considered as a perfect gas. Its thermal conductivity is very low.

Temperature changes are ordinarily considered to have been a result of the addition or subtraction of heat—such as a rise in the temperature of a body due to heat from a fire. Temperature changes in the atmosphere are, however, frequently due to an expansion or compression during which the heat content remains constant. Such a process is known as an adiabatic one and all expansions or compressions caused by vertical motions in the atmosphere may be considered as adiabatic.

The relation between temperature, pressure, and density of a mixture of gases may be expressed by combining Charles' law (density is inversely proportional to absolute temperature), Boyles' law (density is directly proportioned to pressure) and Avogadro's law (density directly proportional to the various molecular weights each multiplied by the ratio of its partial pressure to the total pressure).

Briefly then, if the meteorologist knows the pressure, temperature and humidity, and considers atmospheric expansions and compressions as adiabatic ones, he can compute the results of those processes. Observations of the state of the sky—cloud types, etc.—show him what is occurring. These elements, (pressure, etc.), are the forecaster's tools and will be discussed briefly in the following paragraphs.

Pressure.—Atmospheric pressure is the weight of the column of air above the measuring instrument.

Mercurial barometers, aneroid barometers and barographs are the instruments commonly used for measuring atmospheric pressures. Of the three, the mercurial barometer is the most accurate and satisfactory. The principle of its construction is quite simple. If a glass tube, about 3 feet long, closed at one end, is filled with mercury and inverted so that it stands vertical with its open end immersed in an open vessel of mercury, the mercury in the tube will stand at a level approximately 30 inches above the surface of that in the open

vessel. The height of the mercury column is balanced by the weight of the atmospheric column above the level of the mercury in the open vessel. A vernier scale is provided for accurately reading the length of the mercury column.

In the aneroid barometer, changes in atmospheric pressure cause changes in the distance apart of the opposite faces of a closed metallic box, nearly exhausted of air. These changes are transmitted to a pointer moving over a suitable scale. The barograph is no more than an aneroid barometer so rigged that it gives a pressure trace on a clock-driven drum.

At present in this country, and in most countries of the world, the unit of atmospheric pressure used on the weather map is "millibar." Pressures aloft are also indicated in millibars. The millibar is the direct measure of force and is equal to 1,000 dynes per square centimeter. A pressure of 1,000 millibars is equivalent to the pressure exerted by a column of mercury 29.531 inches high (at 0°C. in latitude 45°).

Isobars are lines, drawn on a weather map, through points of equal barometric pressure. They are analogous to contour lines on an ordinary chart and thus are always closed curves, none of which can intersect. Obviously, the closer the isobars, the greater the change of pressure in a given distance. To continue the analogy, the closer the contour lines, the greater the slope and consequently the more rapid will be the flow of water down the slope. Likewise, on a weather map, the closer the isobars the greater the velocity of the wind. Pressure gradient may be defined as the fall of atmospheric pressure per unit distance, measured normal to the isobars. Crowded isobars indicate a greater pressure gradient. Obviously, the direction of the air flow should be from areas of high pressure to those of low pressure and normal to the isobars. This would be the case if it were not for the effects of the earth's rotation and friction. Friction acts in a direction opposite to that of the air flow and the deflective force of the earth's rotation acts at right angles and to the right of the direction of the air flow—in the northern hemisphere. With sharply curved isobars the centrifugal force must be added to the balance of forces which determines the final direction of the wind. Furthermore, internal friction will result in a different direction with increased altitude—normally a veering. A detailed explanation of the balances is beyond the scope of this work. The final result is that the wind direction at the surface will be at an angle to the isobars, the size of this angle varying with the character of the surface and the force of the wind. Around an area of low pressure—in the northern hemisphere—the surface winds will have an apparent counterclockwise direction but with the flow across the isobars and inward

toward the center. Around an area of high pressure the surface winds will have an apparent clockwise direction with the flow across the isobars outward from the center.

Atmospheric moisture.—Attention has been invited to the fact that virtually all the moisture in the atmosphere is confined to the troposphere. This is evidenced by the lack of cloud forms in the stratosphere. Atmospheric moisture is either in the form of a gas, (water vapor), a liquid, or a solid, (one of the several condensation forms). It is replenished by evaporation from the earth's surface and diminished by condensation and the subsequent precipitation. Moisture, evaporated from the earth's surface is carried upward and diffused by turbulence. Cooling by expansion, contact, or radiation may cause condensation, depending on the degree of saturation.

In observing and measuring the amount of moisture in the atmosphere at any particular point, the relative humidity is first obtained. Relative humidity is defined as the ratio of the amount of moisture present in a given volume of air to the amount that would be present if the air were saturated. It is invariably expressed in percentage.

Having obtained the relative humidity and knowing the corresponding pressure and temperature, the specific humidity and the absolute humidity may be computed if desired. Absolute humidity is defined as the mass of water vapor in a given volume of air, and specific humidity as the mass of water vapor in a given mass of moist air. It may be readily shown that the relative humidity and absolute humidity are extremely variable, whereas the specific humidity of a mass of air varies only when moisture is added to or taken from the mass in question. For this reason specific humidity is very valuable to forecasters in the identification and tracing the movements of the various air masses.

Another measure of atmospheric moisture is known as the *dew point.* It is the temperature to which the air may be cooled without causing condensation. Airways observations, which are broadcast periodically for the benefit of pilots, always give the surface dew point in order that one may tell at a glance how much the actual temperature must fall before fog can occur. The instruments used for determining the relative humidity are the psychrometer, the hygrometer, and the hygrograph. The *psychrometer* is the assembly commonly known as the "wet and dry bulb" thermometer. It consists of two thermometers, mounted together, the bulb of one covered with a saturated wick. When air is passed rapidly by these two thermometers the one with the wet bulb will read lower than the actual air temperature. Its temperature will be the evaporation temperature, which depends on the degree of saturation of the air passing

the bulbs. The relative humidity is obtained by entering a set of tables with the air temperature and the wet bulb depression.

With hygrometers and hygrographs, (recording hygrometers) use is made of the property of certain substances to expand and contract in direct proportion to the changes in relative humidity. The most commonly used of these substances is the human hair—preferably blond with the oil removed—which lengthens with increasing relative humidity. Hair hygrometers are not capable of high precision but they possess the advantage of operating equally well when the temperature is below freezing or above.

Condensation and precipitation forms.—When the water vapor in the atmosphere is cooled below the dew point, condensation occurs.

It is most important that an observer be able to distinguish between the various condensation and precipitation forms—collectively known as hydrometeors. They indicate the hydrodynamical processes which are occurring. Some of the most common of these hydrometeors are briefly defined in the following paragraphs:

Clouds—fine water droplets resulting from the condensation of water vapor in the atmosphere at some distance above the surface. Each droplet condenses on one of the myriad of hygroscopic nuclei always present in the atmosphere. Clouds will be classified and described later.

Fog—a stratus type cloud which reaches the surface or is formed at the surface. Fog will be classified according to the manner in which formed in a later place. In addition, it is classified as dense, moderate, or light, according to visibility conditions at time of occurrence.

Mist—physically the same as fog, but much thinner; so thin that it does not feel wet. Mist is classified as dense, moderate, or light, according to horizontal visibility conditions at time of occurrence.

Haze—consists of dust, salt, or other solid particles in the atmosphere.

Rain—fairly large water drops. Ice crystals falling through clouds collect moisture and then melt. Raindrops are usually not smaller that 5 mm. in diameter. It is also important that an observer distinguish between the types of rain (light, moderate, heavy) and especially between continuous rain and shower rain. Shower rain occurs only with instability conditions.

Drizzle—air filled with fine drops from a low stratus cloud.

Snow—hexagonal ice crystals. Water vapor is transformed from the liquid to the solid state by the sublimation process.

Hail—concentric layers of soft, semitransparent ice, often with a clear ice core. Hail can occur *only* in thunderstorms.

Sleet[1]—melting snow or a mixture of melting snow and rain.

Grains of ice[1]—frozen raindrops.

Density.—The density (mass per unit volume of any gas), is directly proportional to the pressure and inversely proportional to the absolute temperature.

$$\text{density} = \frac{p}{RT}$$

where p=pressure, T=absolute temperature, and R=gas constant.

As is commonly known, the density of the atmosphere, and hence its pressure, decrease upward. Since the atmosphere is a mixture of gases and water vapor, R is variable, and the computation of the density must also take into account the amount of water vapor present.

Keeping the above formula in mind, it is apparent that cold air will be of greater density than warm air when p and R are the same. Further, since the weight of a given volume of water vapor is approximately five-eighths that of an equal volume of dry air, it is evident that dry air is of greater density than moist air. In other words, dry and cold air is heavier than warm moist air.

Remembering that the rate of fall of temperature with increased altitude is seldom constant and that the water vapor distribution is extremely variable, it is seen that the rate of decrease of density with increased altitude cannot be a constant one. It is partly because of this that the pressure type altimeter cannot be depended on to accurately indicate the altitude of an airplane. The altitude of any point above the earth's surface depends on the density of the air between that point and the earth. In other words, the altitude cannot be expressed in terms of pressure alone, but must include temperature and moisture content. The altimeter is no more than an aneroid barometer, calibrated to indicate altitudes in feet for average conditions of temperature and moisture content. When these conditions are not average, and they seldom are, an error will be introduced.

Then again, since the air is constantly in motion, one cannot expect a constant pressure at any particular point. A rising barometer indicates air of greater density or more air over the instrument and if the addition of air or increase in density occurs wholly or partially above the level of the airplane, its altimeter will indicate a level lower than its actual altitude. This same type of error is introduced when there is a difference in pressure between the point of departure and the destination of airplane. Roughly, in the lower layers of

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[1] NOTE.—These definitions for sleet and grains of ice have recently been decided upon by international conference. That given for grains of ice describes what is commonly known as sleet in this country.

the atmsophere, a change of pressure of one inch of mercury would correspond to a change in altitude of 1,000 feet. Pressure changes at the surface of this magnitude are rare, but the combined effect due to difference in pressure at point of departure and destination and a difference in the elevation of these two points may be quite large.

TEMPERATURE AND STABILITY CONDITIONS

In defining troposphere and stratosphere, attention was invited to the fact that there is normally a fall of temperature with increased altitude in the troposphere. The rate of this fall varies with the characteristics of the air and it may happen that there is an increase in temperature with increased altitude in certain layers of the air mass. This decrease of temperature with increased altitude is known as the temperature *lapse rate*. To investigate the lapse rate in any air mass we draw a diagram in which temperature is plotted against altitude, as in figure 94. This gives a curve whose slope indicates the way the temperature changes with altitude.

By *stability* is meant a condition of the atmosphere that resists vertical motions therein. That is a condition such that any element removed from its original position will differ from its surroundings in density in such a way that it will tend to return to its original position. *Instability* is the opposite; an element once started will continue to move.

One knows that the air pressure always decreases with any increase in altitude. Therefore, any sample of air moved from a lower to a higher altitude will expand. This expansion will, of course, cause the temperature of the moving element to decrease. As long as this sample is unsaturated the decrease in temperature due to decreased pressure and increased volume will be approximately 1° C. per 100 meters increase in altitude. This is known as the *dry adiabatic lapse rate*. That is, the rate at which unsaturated air will always cool if no heat is added to it nor removed from it during its displacement. Naturally if it is caused to move downward instead of upward its temperature will increase at the same rate.

Now if the moving element is saturated the lapse rate will differ. As soon as the initial expansion, with its consequent cooling, takes place, a small amount of condensation occurs. This condensation liberates a certain amount of heat, the latent heat of condensation. This means that the net cooling is less than the dry adiabatic. This rate is known as the *moist adiabatic lapse rate*. It is not constant but varies inversely with the temperature. It is also affected by the pressure. It is less than half the dry adiabatic rate at sea level and high temperatures and approaches it at very low temperatures.

Air masses whose lapse rates are less than the moist adiabatic are absolutely stable, those whose lapse rates are greater than the dry adiabatic are absolutely unstable and those whose lapse rates lie between the two are conditionally unstable. The various conditions of stability are illustrated in figure 94.

The extremely stable layers occasionally found in the troposphere, through which the temperature increases with altitude, (inversions), are most often found in anticyclones and over regions where the

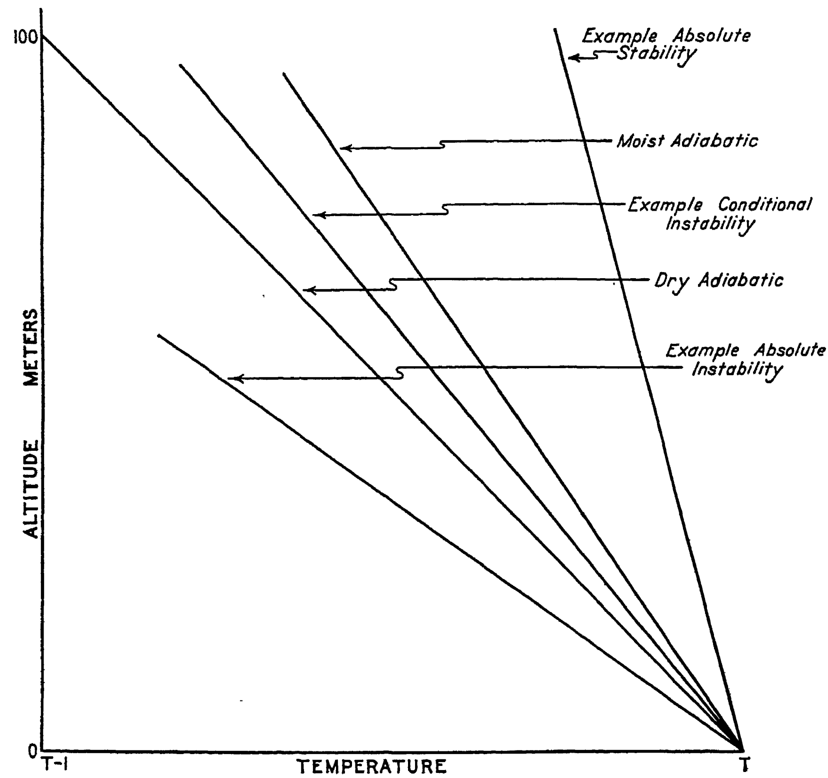

FIGURE 94.—Lapse rates showing various conditions of stability.

local circulation is such that there is advection of a warm layer of air over a cooler one. When a layer of air is cooled on its lower side or heated on its upper side an inversion is formed. This cooling from below or heating from above may be caused in any one of several ways. For example, when a layer of air sinks, it is compressed, but more so on its upper side than its lower one. That is to say, its thickness becomes less, and since the process may be considered to be adiabatic, the top of the layer is heated more than the bottom. Clearly, then, a sinking layer of air will have its lapse rate becoming increasingly stable—and often an inversion is formed. An in-

version formed in this manner is known as a *subsidence inversion.* This condition persists over southern California and the adjacent portion of the Pacific. It is often quite pronounced and may be found throughout the greater portion of the year. Its altitude varies from day to day and the temperature of its top is often as high as 100° F. The explanation of its formation and persistence is as yet rather vague and unsatisfactory but it is undoubtedly partly due to the heating of the air over the inland desert regions and the cooling of that passing over the cold coastal waters.

The thermometer and the thermograph are the instruments used for measuring atmospheric temperatures. The units of temperature in the United States are degrees fahrenheit for surface temperature and degrees centigrade for those aloft. The sensitive element of most of the thermographs is a bimetallic strip—two metals with different coefficients of expansion fused together in the arc of a circle. Changes in temperature cause the strip to straighten out or become more curved; the movement is transmitted to a pen arm which traces the temperature on a clock-driven drum.

Ice formation on aircraft.—When engaged in cold weather flying the pilot should always bear in mind the danger of ice forming on his airplane. Ice on the wings of an aircraft not only increases the load but also alters the aerodynamic characteristics of the airfoils in such a way that their lift is reduced. Once started it forms very rapidly and the combined effect of increased load and reduced lift may be disastrous. Then too, the controls may become frozen due to a coating of ice.

When flying in clouds, fog, or through rain, mist, or drizzle with temperatures at or below freezing this danger exists. As soon as ice is observed the pilot should land if possible; if not possible to land he should immediately seek a warmer altitude. In this connection it should be mentioned that a cold mass of air becomes relatively shallow after it has moved some distance from its source and warmer air is often above. Thus it is often to the pilot's advantage to climb to a higher altitude in his search for a warmer level.

Ice formation in the carburetor is also of concern to the aviator. In present day engines the temperature drop through the carburetor is tremendous, frequently to well below freezing temperatures. Now if the air is very moist, as indicated by high relative humidity (temperature and dew point close together), some ice will likely form. This becomes very dangerous when the specific humidity (actual water content), is high. These are conditions which often prevail over the ocean. This, of course is guarded against by the judicious use of the carburetor preheat.

Winds.—Wind may be defined as approximately horizontal movement of the air.

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It has been stated that, due to the rotation of the earth, air movement in the northern hemisphere has an apparent deflection to the right. The cause of this is commonly referred to as the deflective force of the earth's rotation. Actually there is no force but rather a turning of the earth under the moving air. This is most readily explained by considering a sector of the earth's surface with the North Pole as its center. The rotation of the earth from this perspective is counterclockwise and thus a particle moving from the pole in any direction will actually arrive at a position to the right of the point it started toward due to the rotation of the earth. In like manner, if the motion starts from any point in the northern hemisphere, the earth has a component of rotation in the same direction about an axis through that point. Going a step further, it may be shown that this "deflective force" is a maximum at the pole and zero at the equator.

Internal friction in moving air carries the effect of surface friction upward, but in a constantly decreasing amount with the net result that at some altitude (depending on the velocity of the moving air and the character of the surface) the effect of surface friction is entirely lost. At this point the balance of forces which determine the direction will cause the wind to nearly parallel the surface isobars. There will be a veering of wind with increasing altitude up to the level where the effect of surface friction is negligible.

No discussion of wind, however brief, should omit the law enunciated by Professor Buys Ballot of Utrecht in 1850 which gives the relation of wind flow to atmospheric pressure. Quoting in part: "In the northern hemisphere, if a person stands with his face to the wind the region of lower pressure will be on his right hand and somewhat behind him, the region of higher pressure lies on his left hand and somewhat in front of him." Although Buys Ballot's law holds in all cases it is to be noticed that only when the isobars of a cyclone are circular and concentric does it indicate the direction of the center.

Bumps.—The zone of turbulent air, next the surface of the earth, has been aptly termed the "surf-zone" of the atmosphere and in it the aviator often experiences considerable bumpiness. All bumps may be said to be due to deflections in the horizontal wind, either upward or downward, and not due to "air pockets" as was formerly believed. The smoke from a stack will often give evidence of the amount and character of turbulence.

Figure 95 indicates the character of turbulence in the vicinity of various irregularities.

With strong winds, a violent downward flow may be expected on the upwind side of an abrupt discontinuity such as is shown at A.

Obviously a plane flying downwind at too low an altitude over this point is in danger of being thrown downward into the side of it.

Another position where violent vertical components may be expected is in cumulonimbus clouds (thunderstorms). Here a vertical component of 100 miles an hour is not uncommon. The result of flying from relatively horizontal moving air abruptly into such an upward current can be readily imagined. The experienced aviator has great respect for, and avoids flying into this type of cloud.

The bumpiness experienced on a hot summer day is that due to local convection caused by unequal heating on the surface. In an unstable air mass this unequal heating is often the cause of local thunderstorms. They will be discussed later.

Over shore lines, rivers, and in fact any place where there is an abrupt change in the character of the surface (hence the amount of surface friction), there will be a deflection of the horizontal air flow and a "line of bumps." This line will closely follow the contour of the shore line or river. This effect is quite noticeable over Santa Rosa Island with onshore winds of some velocity. The "line of bumps" will be carried downwind a certain distance. Figure 96 shows anemobiograph records of wind flow with a gusty wind and a steady wind.

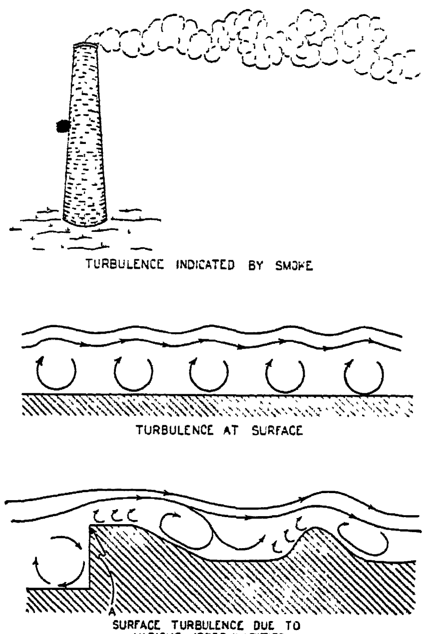


FIGURE 95.

Wind instruments.—Many types of instruments have been constructed for observing the force and direction of the winds. For obtaining the force of the wind, the "cup type" anemometer is most commonly used. It is no more than a flowmeter—i. e. it measures the flow of air passing the instrument.

The direction is obtained with a simple wind vane or anemoscope. Wind observations on shipboard must be corrected for course and speed of the ship. Space provided does not allow a detailed description of the various types of wind instruments. The anemobiograph records instantaneous velocities and directions on a clock-driven drum. With this instrument, velocities are obtained from a pitot tube—the pressure opening being in the end of the wind vane.

Figure 97 gives the Beaufort scale—used for estimating wind velocities. In order to intelligently read a forecast it is necessary to know the velocities corresponding to the terms used.

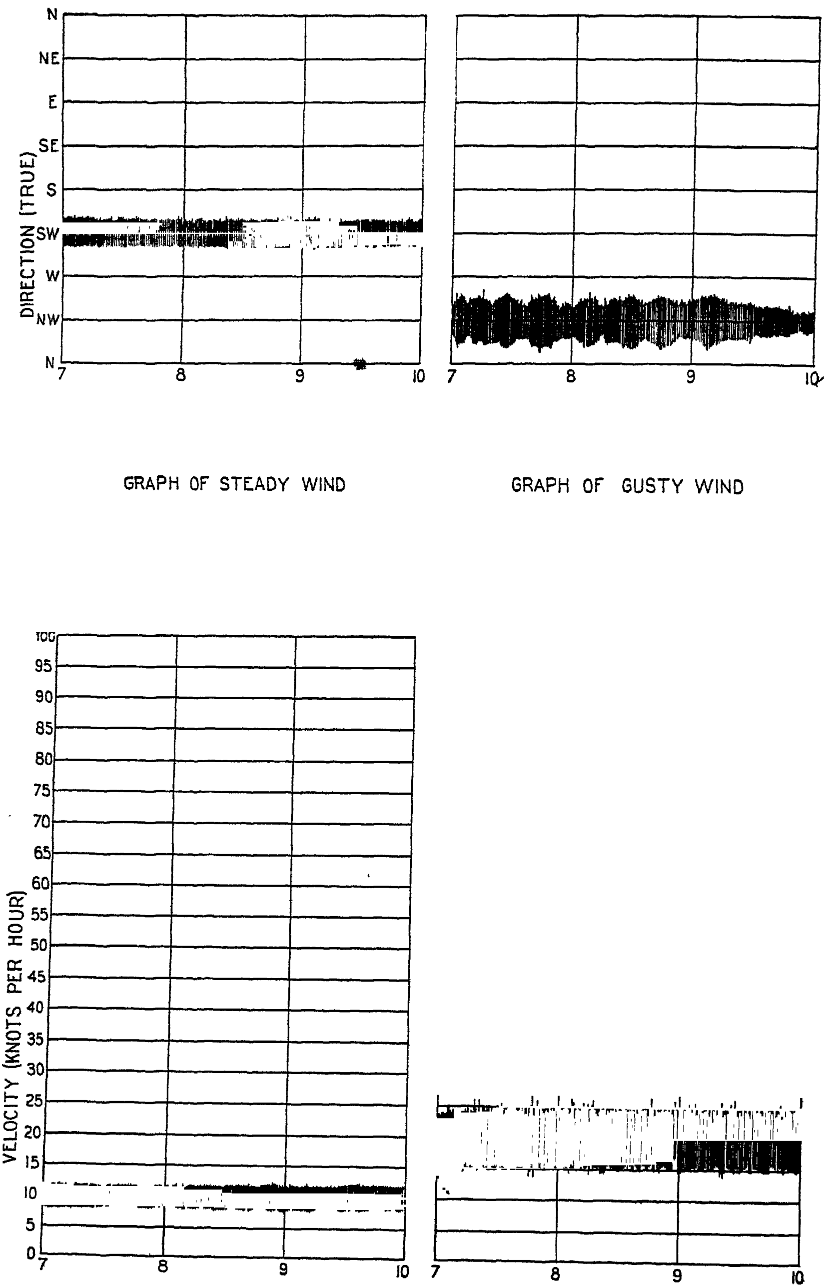


FIGURE 96.

Upper air observations.—It is essential, for a thorough analysis of atmospheric conditions, to have a vertical cross-sectional picture of the pressure, temperature, and moisture distribution as well as a knowledge of the wind force and direction at various levels. Aside from this, it is extremely desirable that the winds aloft be known when making cross-country flights.

Beaufort scale of wind velocities

Descriptive word [1]	Velocity (miles per hour)	Specifications for estimating velocities
Calm	Less than 1	Smoke rises vertically.
	1 to 3	Direction of wind shown by smoke drift but not by wind vanes.
Light	4 to 7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
Gentle	8 to 12	Leaves and small twigs in constant motion, wind extends light flag.
Moderate	13 to 18	Raises dust and loose paper; small branches are moved.
Fresh	19 to 24	Small trees in leaf begin sway: crested wavelets form on inland waters.
	25 to 31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
Strong	32 to 38	Whole trees in motion; inconvenience felt in walking against the wind.
	39 to 46	Breaks twigs off trees; generally impedes progress.
Gale	47 to 54	Slight structural damage occurs (chimney pots and slate removed).
	55 to 63	Trees uprooted: considerable structural damage occurs.
Whole gale	64 to 75	Rarely experienced; accompanied by widespread damage.
Hurricane	Above 75.	

[1] Except "calm," these terms not to be used in reports of velocity.

FIGURE 97.

Winds aloft are obtained by observing, with a theodolite, the altitude and azimuth angles of a small hydrogen (or helium) filled balloon at intervals of 1 minute after release. The balloon is first carefully inflated so as to have a definite known free lift. It then has a practically constant rate of ascent, and thus the observer knows its altitude at any instant. It follows then, with the altitude of the balloon known at all times and the altitude and azimuth angles observed at the end of each minute, the computation of the horizontal movement of the layer which the balloon is in during a minute interval is relatively simple. This method gives the average direction and velocity for the various layers rather than that for any particular level.

Observations of pressure, temperature, and humidity aloft are made by carrying an *aerograph* aloft in a plane. This instrument records the three elements on a single clock-driven drum. It is simply a combination of the barograph, hygrograph, and thermograph with the case scientifically streamlined and ventilated.

The most recent development in the taking of upper air observations is the radiometeorograph. After years of experiment this instrument is nearing perfection and is now actually in use at certain selected stations throughout the country. It consists of the same three elements just mentioned (barograph, hygrograph, thermograph), and a small radio transmitter which sends out impulses for the varying values of pressure, humidity, and temperature. These

impulses are received at the station, and by use of the calibration curve for the instrument the actual values are obtained. The transmitter and aerograph are carried aloft by hydrogen- (or helium-) filled balloons. This allows soundings to be taken to great heights. Another advantage, of course, is that they are not grounded by bad weather conditions. Experiments are now under way to enable the winds aloft to be determined by using this instrument.

THE GENERAL CIRCULATION

Because very little is known of what goes on in the stratosphere and since the circulation in that region (as far as has been discovered) has comparatively little effect on the weather in the troposphere, this discussion is confined to the circulations of the troposphere.

It has been determined that the temperature of the surface of the earth in its entirety varies an exceedingly small amount, if any, during the course of many years. In other words, the earth reradiates an amount of heat into space equal to that which it receives from the sun. Then again, we know that the earth receives more heat in tropical regions than it reradiates, a net gain of heat in tropical regions and a net loss in polar regions, yet their *average* temperatures are practically constant. This being the case there must be a horizontal movement of heat from tropical regions to polar regions. The manner in which this heat transfer is effected is the cause of a greater portion of the weather in the middle latitudes.

Most schools, in the study of physical geography, teach the old generally accepted theory of atmospheric circulation. As many readers know, this theory consisted mainly of locating and defining certain "belts"—the Doldrums, the Trades, the Horse Latitudes, the Prevailing Westerlies, and the Polar Caps. While this theory is logical and practicable, it does not tie in well with the modern explanation of the various weather circulations and phenomena. In recent years Professor Bergeron has advanced a scheme which is logical, easily understood, and in addition affords a starting point for our study of the various circulations of the middle latitudes.

Figure 98 represents with fair accuracy a model of the average wintertime circulations and pressure distributions actually observed in the northern hemisphere. This average condition is due to the actual distribution of land and water and the resulting variations in surface temperatures. Attention is invited to the fact that these circulations act in a manner similar to a system of interlocked gears and bring air from equatorial regions to polar regions or from polar regions to equatorial ones. Regions where the wind flow of one system converges with that of another are hatched and are the regions

where *fronts* are generated. Those regions where the flow is divergent represent localities where fronts are destroyed.

In this connection a *front* is defined as a surface of discontinuity between two air masses of different physical characteristics.

The fronts shown at DD and CC are known as equatorial fronts and those at AA and BB as polar fronts. The Arctic front, that between the air over the polar cap and the indicated centers of action

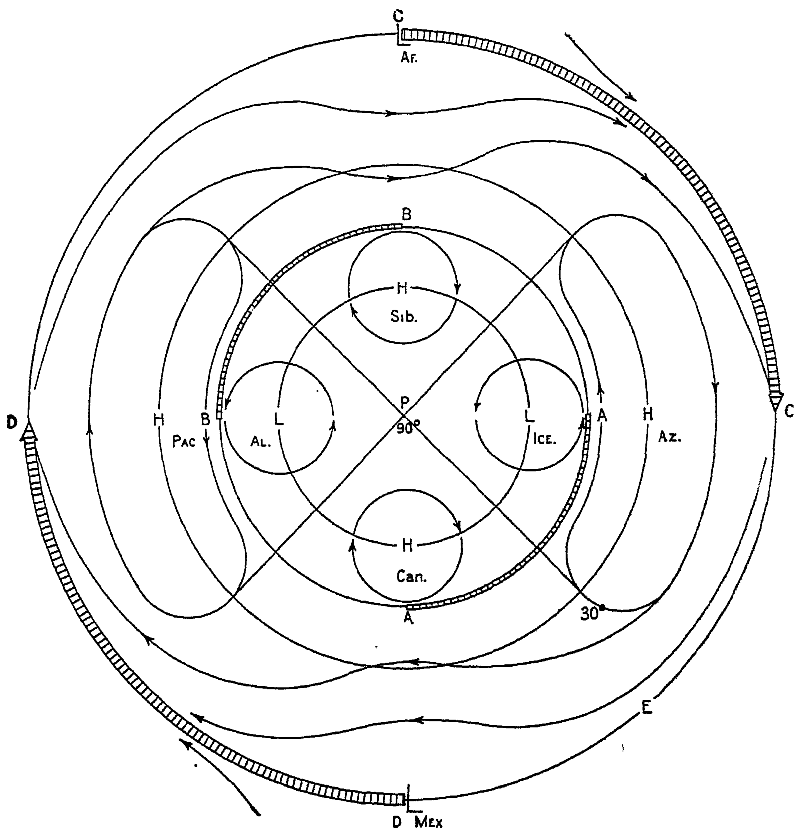


FIGURE 98.—Schematic general circulation.

to the south, is not shown. True Arctic air plays a very minor role in the weather of the middle latitudes.

It should be remembered that this is a schematic diagram representing average wintertime conditions and not that found in any one individual case. The polar front, which plays such an important role in the weather of the middle latitudes, is often distorted and broken up; other minor fronts may be generated and destroyed.

Cyclones.—Under the discussion of pressure, it was stated that around an area of low pressure (in the northern hemisphere) the

wind flow is counterclockwise. This type of circulation is properly termed a cyclone, though to most laymen the name "cyclone" signifies the violent local atmospheric vortex which is properly termed a tornado.

Cyclones may be divided into two main types—the tropical cyclone and the extratropical cyclone. In the Atlantic the tropical cyclone is commonly known as a *hurricane*, and in the Pacific as a *typhoon*.

According to present theory the tropical cyclone is formed on the equatorial front, during the season of the year when this front is farthest north (summer) and the convergence is most marked. After its development it moves slowly westward and gradually northward. Provided its path is not blocked by contrary circulations, it recurves to the eastward when it is far enough from the equator for the deflective force of the earth's rotation to have sufficient effect. When fully developed all traces of the equatorial front are destroyed and the distribution of rainfall, wind, and pressure is symmetrical about its center. Prior to its recurvature the diameter of this type of storm is usually between 300 and 500 miles and its speed of translation between 5 and 15 miles per hour.

The energy source in the tropical cyclone is the heat of condensation of the water vapor, released by the expansional cooling of the rising warm moist air. When the storm passes inland its energy source is shut off, and it will either assume the character of an extratropical cyclone or become dissipated, depending on the air mass distribution at the point it passes inland.

The tropical cyclone with its slow speed of translation and comparatively small diameter, together with the fact that its location and direction of movement is normally known, should be comparatively easy to avoid. Flying in this type of storm should never be attempted. For a complete description of the storm itself the reader is referred to any standard meteorological text book.

The extratropical cyclone (or low) is formed along the surface of discontinuity (front) between two large masses of air having different properties, viz: a warm moist current of air traveling northward and a cold current (to the west of it) traveling southward.

As long as the flow is parallel, the front will be in equilibrium and the weather will be that which can occur wholly within each of the air masses. However, as soon as one current has a component of motion in toward the front, a wave will form and this wave may subsequently develop into an extratropical cyclone. Figure 99 illustrates the plan view (that shown on a weather map) of such a development. Figure 100 shows fully the developed cyclone model with vertical sections through the indicated portions.

As this storm develops further, the cold air in the rear moves faster than the warm front and the warm sector is cut out. When this occurs the storm is said to be occluded. Examining the vertical sections shown in figure 100 it will be seen that the warm air rides up over the cold air in the front of the storm, and cold air pushes under warm air in the rear of the storm.

Where warm air supplants cold air at the surface the discontinuity is known as a warm front, and where cold air supplants warm air at the surface it is known as a cold front. Warm fronts have a rather gradual slope (about 1 in 100), whereas cold fronts are abrupt.

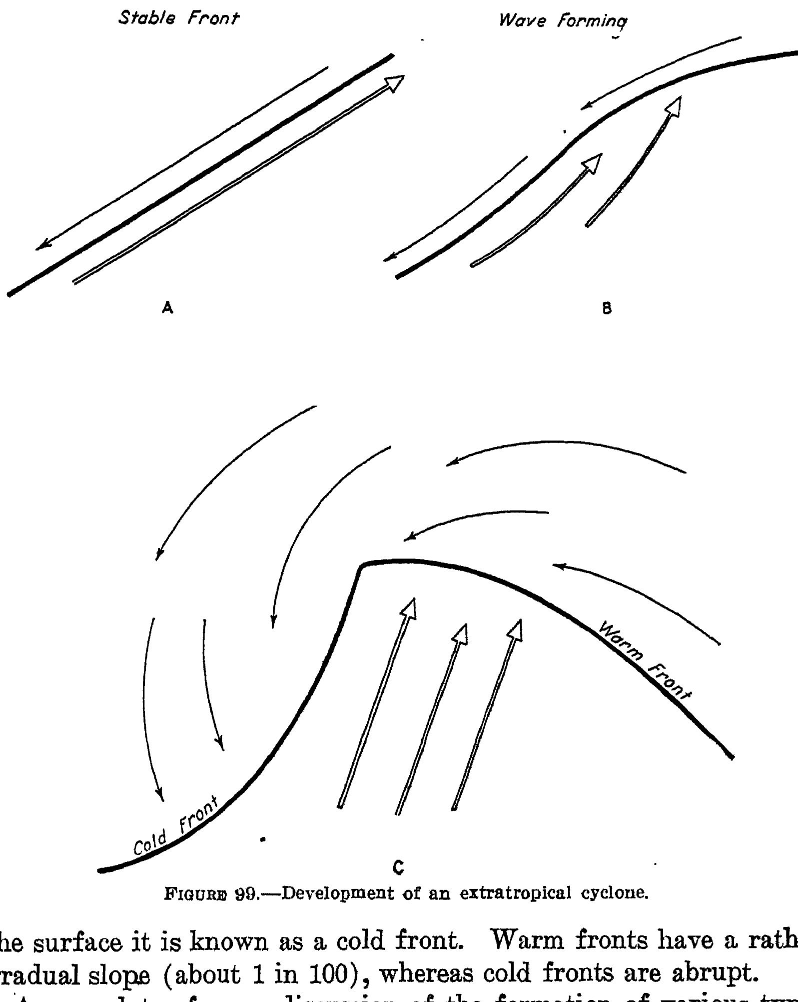


FIGURE 99.—Development of an extratropical cyclone.

As seen later from a discussion of the formation of various types of clouds, warm fronts produce strata-form clouds, continuous or intermittent rain, and gradually lowering ceiling with accompanying reduced visibility, whereas cold fronts produce thunderstorms, line squalls, and turbulent type clouds.

Before leaving this discussion it should be mentioned that all cyclonic circulations are characterized by convection (or rising air).

Anticyclones.—It has been stated that the circulation around an area of relatively high barometric pressure (in the northern hemi-

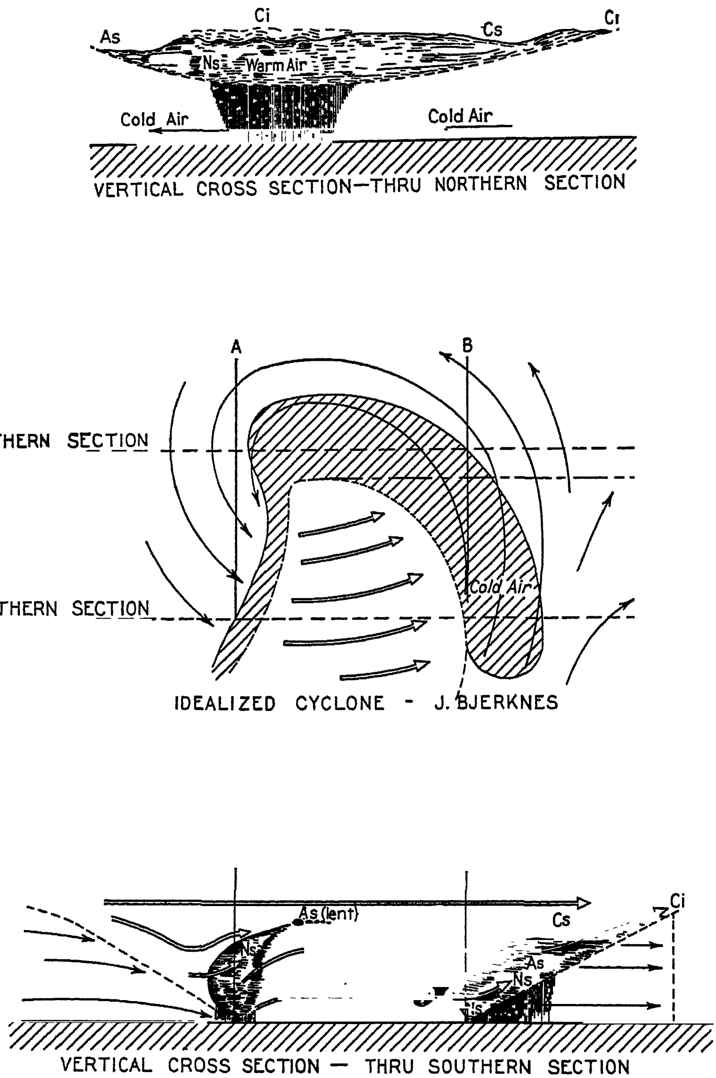


FIGURE 100.

sphere) is clockwise. Actually the air mass of an area of high pressure is gradually subsiding with the result that the winds blow spirally outwards in the layers next the surface of the earth. Except in cases where the air mass of such an area has been heated from below (due to passage over warmer surface) one may expect a very

stable vertical temperature distribution. Furthermore, the effect of sinking or subsidence in an anticyclone tends to increase the stability often to such an extent that inversions are produced. This tendency counteracts the decrease in stability due to heating from below, from being carried very high and thus may prevent the formation of any showers or thundershowers within the air mass.

Trade winds, prevailing westerlies, and horse latitudes.—With the Bergeron scheme of the general circulation in mind, the explanation of the Trade Winds, the Prevailing Westerlies, and the Horse Latitudes becomes relatively simple. The circulation around the oceanic semi-permanent anticyclones gives northeast winds on the southern side, westerly winds on the northern side, and light variable winds along its axis.

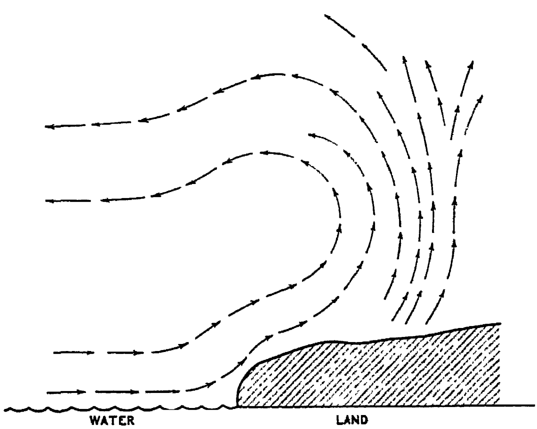


FIGURE 101.—Sea breeze circulation.

Land and sea breezes.—These winds occur in coastal regions and are due to the unequal heating in the land and adjacent water at times when the pressure gradient is weak. During the day the land becomes warmer than the adjacent water, thus heating the air over it and reducing its density. The cooler air over the sea then flows in and forces the warm air to rise. This inflowing air from over the water is known as the *sea breeze* and is most pronounced when the heating of the land is at a maximum.

At night the land is cooled to a greater extent than the water, and a reverse circulation which is known as the *land breeze* occurs.

Figure 101 shows the sea breeze circulation.

The sea breeze seldom extends more than 15 miles inland and is always much more pronounced than the land breeze. Its depth is generally in the neighborhood of 1,000 feet.

Monsoons.—The seasonal difference in the heating and cooling of large bodies of land and adjacent water often cause the seasonal

winds known as the monsoons. The most pronounced monsoon winds are those of the China Sea and the Indian Ocean. In the winter, as a result of the extremely low temperature over the continent of Asia an extensive anticyclone develops. Its circulation together with that of the semipermanent cyclone (caused by high temperature), which then overlies Northern Australia and the adjacent portions of the Indian Ocean, results in the northeast or *dry* monsoon which is characteristic in the winter months. In midsummer as a result of the heating of the land, the Asiatic continental anticyclone is replaced by a cyclonic area, and an anticyclonic area develops over Australia. This reversed circulation brings the southwest or *wet* monsoon.

In many places over the surface of the earth, local storms, each of which bears a name familiar to the inhabitants of the particular locality, occur. Examples of these are the *Santa Ana*, the *Tehuantepecer*, the *Papagaya*, and the *Chubasco.*

The first three are dry winds of constant direction and at times of near hurricane force. The Santa Ana occurs on the coast of California in the vicinity of San Pedro, and the Tehuantepecer in the gulf off the west coast of Mexico from which it gets its name, while the Papagaya occurs along the west coasts of Honduras and Nicaragua. All of these storms are most apt to occur in the winter time when pressure gradients to the NE. or E. are great.

The Chubasco is the violent squally condition usually associated with thunderstorms that occur along the west coast of Mexico when the circulation is such that warm moist air strikes and is forced up over the high mountains that lie along the coast.

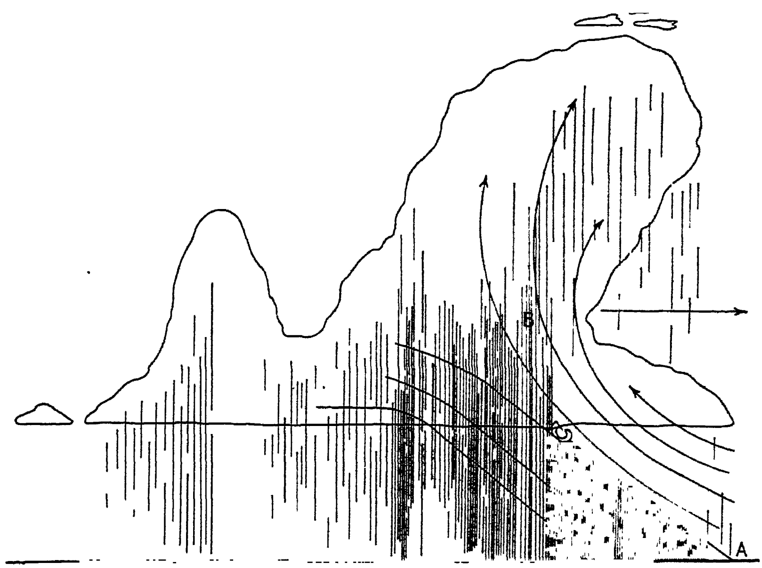
Thunderstorms.—The thunderstorm is one of the greatest hazards the weather offers to safe aerial navigation. The cumulonimbus or thunder cloud contains violent vertical wind currents and generates a great amount of electrical energy. Flying through such a cloud is extremely dangerous and either the shearing force of the violent vertical current or the electrical discharge may cause the destruction of the plane. Furthermore, the hail which often accompanies such a storm is apt to cause irreparable damage. Then again the reduced visibility due to heavy rain which accompanies this type of storm makes flying dangerous.

Thunderstorms may be divided into two classes—the *local convection* type and the *line squall* type. The formation of the two are considerably different, but, when formed, the mechanics of each is identical.

The local convection type is formed by the unequal surface heating of warm, moist, unstable (or conditionally unstable) air. For example—air over a plowed field is heated during the day more

than the air over an adjacent wooded area. It thus becomes lighter and the cooler air flows in and forces it upward. This rising air expands as it moves upward and is cooled adiabatically. It will continue to move upward as long as it is warmer than the surrounding air until finally condensation occurs, and a cumulus cloud forms. As long as the convection continues this cloud will build up and develop into a cumulonimbus which will be carried along with the general wind current. The cumulonimbus cloud is always characterized by false cirrus or anvil-shaped top.

Figure 102 shows a cross section of typical cumulonimbus.



VERTICAL CROSS SECTION TYPICAL THUNDERSTORM

FIGURE 102.

In front of the cloud the surface wind is directed toward it and gradually deflected upward into the vertical ascending current. In the rear of the cloud the air is gradually descending and at the surface is in the direction of the general wind current. The descending air in the rear is cooler (precipitation having occurred) and a front (AA′) is established below the cloud between the warm ascending air and cool descending air. Rain commences after the false cirrus or anvil has formed and the largest drops will be found in the front of the cloud. B marks the portion of the cloud where the vertical current is at a maximum. Here raindrops are broken up, thus causing the area in the immediate vicinity to become positively charged, the negative ions being carried into the body of the cloud. The earth itself always maintains a negative potential.

Thus when the difference in potential between the areas of the cloud in the vicinity of B and (1) the body of the cloud, or (2) the earth or (3) another cloud, becomes great enough, there will be an electrical discharge or lightning flash from B to one of the other points. Sometimes the body of the cloud may become so greatly negatively charged that the earth is positive in respect to it; when this occurs there will be a discharge from the earth to the cloud.

The vertical velocity of the ascending current has been estimated to vary between 45 and over 100 knots. One pilot who was caught in such a current and lived to tell the story relates that he nosed straight down with full power on and yet his altimeter still showed him to be ascending.

Rain drops are sometimes carried upward in this current until they are frozen, then spill out the forward part, fall until caught in the up-current again and in this manner have several concentric layers of ice frozen one on the other. Finally, they become so heavy that the up-current can no longer support them and they fall as hail. Hail stones vary in size from small pellets to several inches in diameter. From the size and density of the hail stone it is possible to estimate the maximum vertical velocity in the cloud.

The *line squall* type of thunderstorm is started by the warm air in front of a cold front being forced upward by the incoming cold wedge of air. When the moisture and stability conditions are favorable thunderstorms will occur along the entire length of the cold front (often several hundred miles long) and will be so close together that it is impossible to avoid them.

The base of the cumulonimbus is often quite low, about 1,000 feet while its top may reach the base of the stratosphere. Thus it is clear that if a pilot finds it impossible to fly around a thunderstorm formation he should fly before it until he finds a suitable place to land.

Tornado.—A tornado is a violent counterclockwise atmospheric vortex of small diameter (100 to 1,500 feet) and appears as a well defined funnel-shaped cloud reaching the surface. It is of relatively short duration and occurs at some point along a well defined cold front. It nearly always travels toward the northeast at a speed of 20 to 25 miles per hour. The sudden decrease of pressure near its center has frequently caused buildings in its path to explode. The winds around the vortex are of tremendous velocities—estimated as high as 500 knots.

A tornado over the water is known as a *waterspout*. They may be frequently observed in tropical waters and are smaller and less violent than a tornado of the middle latitudes.

CLOUDS

The proper identification of clouds is of much importance to the meteorologist in that they indicate the physical process which the atmosphere must have undergone to produce them. In addition, recognition of the cloud types fixes their altitude within certain limits.

By international agreement clouds are classified in ten principle types according to form, as follows (illustrations from Circular S, Weather Bureau, U. S. Department of Agriculture):

FIGURE 103.—Cirrus.

Cirrus (Ci) figure 103.—Detached clouds of delicate fibrous appearance frequently resembling feathers and of a whitish color. They are composed of minute ice crystals and are the highest of all clouds. Their altitude will vary with season and latitude but will average somewhere in the neighborhood of 10 kilometers (30,000–35,000 feet).

Cirrostratus (Cs) figure 104.—A very thin high white sheet giving that portion of the sky covered a milky appearance. Their altitude will average about 8 kilometers (25,000 feet).

Cirrocumulus (Cc) figure 105.—This type of cloud is commonly termed *mackerel sky* and is composed of small globular masses with very little shadow. Normally they form at an altitude of from 5 to 8 kilometers (16,000 to 25,000 feet).

FIGURE 104.—Cirrostratus.

FIGURE 105.—Cirrocumulus.

Altostratus (As) figure 106.—This type appears as a thick greyish sheet through which the outline of the sun or moon can be seen.

Altocumulus (Ac) figure 107.—Is composed of fairly large globular masses, thicker and heavier appearing than cirrocumulus. They are normally considerably shaded and often very closely packed.

Altostratus and altocumulus are normally found between 3 and 6 kilometers (10,000 to 20,000 feet).

Stratocumulus (Sc) figure 108.—Appear as large globular masses or rolls of dark clouds. Their altitude is normally less than 1 kilometer (3,300 feet).

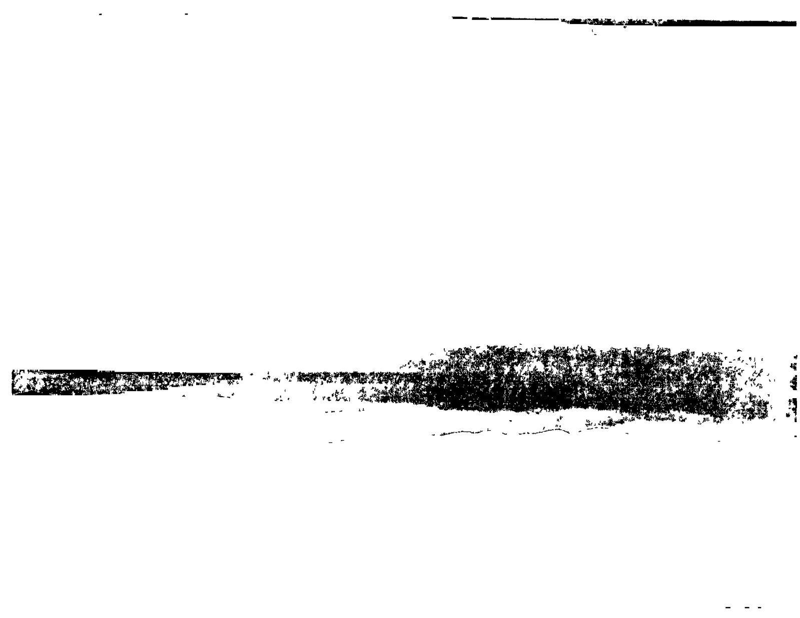


FIGURE 106.—Altostratus.

Nimbostratus (Ns) figure 109.—This type has been described as a thick irregular mass of dark cloud from which steady precipation is falling but is not considered a separate classification by most meteorologists. It is used more often coupled with some other cloud type to denote active precipitation.

Cumulonimbus (Cb) figure 110.—This type is the thunderstorm or shower cloud. It appears as towering masses normally in the shape of turrets or anvils and almost invariably capped by a thin veil of cirrus. Its base is usually quite low but its top often extends to great heights—even to the cirrus level.

Cumulus (Cu) figure 111.—Large globular masses with flat bases and dome-shaped tops. The altitude of the base will vary but will normally be about one kilometer (3,300 feet) or less.

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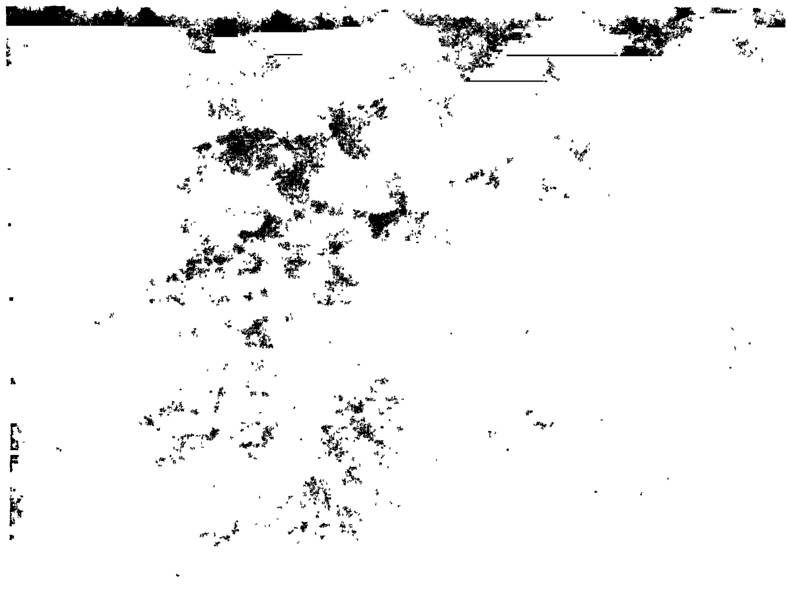

FIGURE 107.—Altocumulus.

FIGURE 108.—Stratocumulus.

FIGURE 109.—Nimbostratus.

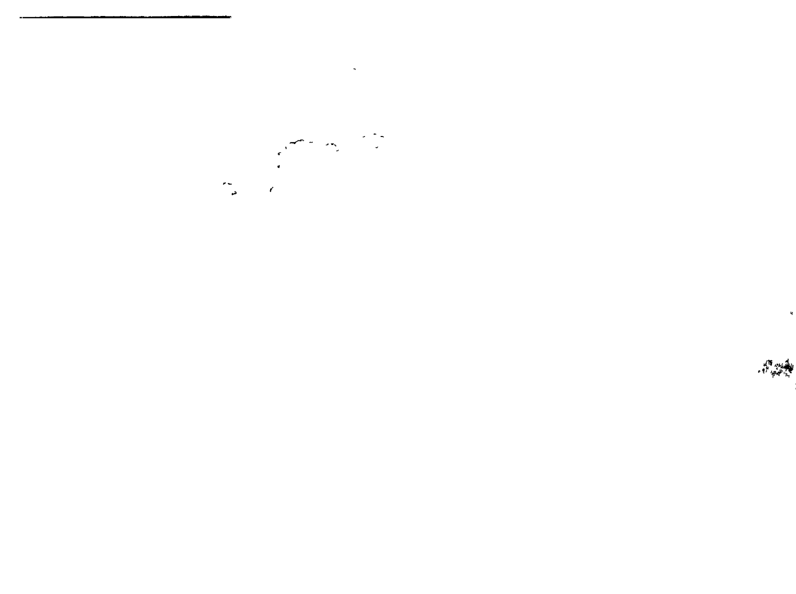

FIGURE 110.—Cumulonimbus.

FIGURE 111.—Cumulus.

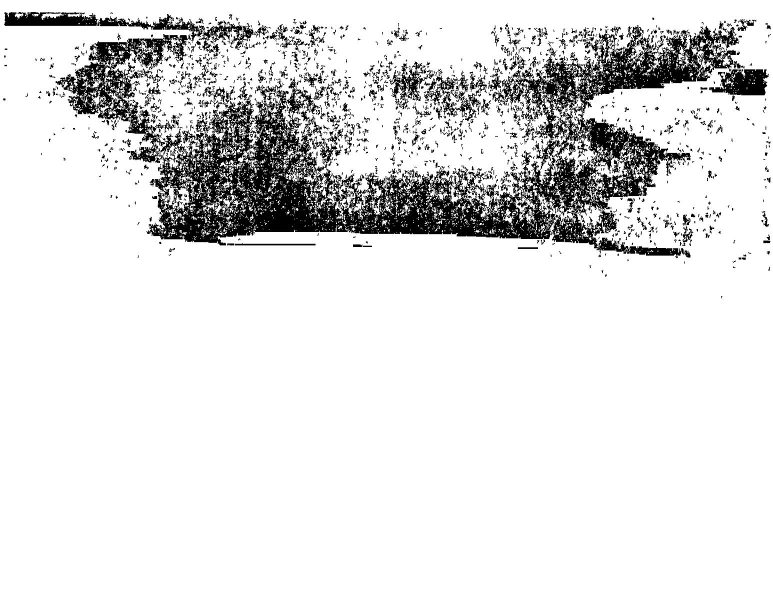

FIGURE 112.—Stratus.

Stratus (St) figure 112.—A thick uniform layer of cloud which appears the same as fog except that it is at some altitude above the surface.

Formation.—For the most part, clouds are formed either by an advective (horizontal movement of air) or convective (vertical movement of air) process, or a combination of the two. Cumulo-form clouds are of the convective type, formed by the expansional cooling (to the condensation temperature) of ascending unstable or conditionally unstable air. The initial lifting which starts the convection may be caused either by unequal heating at the surface or by forced lifting such as is the case with the warm air before a cold front. Then again the initial lifting may be due to a current of warm moist air riding up over mountains or other large scale surface irregularities.

Strata-form clouds are caused by the advective cooling of relatively warm moist air due to its passage over a cooler surface. The best illustration of this is the warm front cloud system. The slope of this front is so gradual that condensation will normally be due to cooling of the lower surface of the warm air by the cold wedge.

Though it is true that most strata-form clouds occur along the surface of discontinuity between the air masses, they may also form entirely within an air mass when, for some reason, an inversion is formed. The formation of an inversion normally results in the cooling of the layer of the air at the base of the inversion and when there is sufficient moisture in the air mass, condensation will result. The best example of this is with an inversion formed by turbulence due to surface friction. Assume an initial lapse rate quite stable as that shown in figure 113 at AD. If for some reason the wind flow is increased so that considerable turbulence is caused in the layer next the earth's surface, that portion of the lapse rate in the turbulent zone will be brought toward the adiabatic (AE) while the lapse rate above the turbulent zone will be undisturbed. That being the case the final lapse rate will be AECD and it becomes evident that there must be a maximum cooling at the top of the turbulent zone. Strato-cumulus clouds will be the result provided there is sufficient moisture.

Sea salt, dust, smoke and other impurities provide the necessary hygroscopic nuclei for condensation.

Fog.—Fog is really a stratus cloud cover that forms at the ground or close to it so that it seriously restricts the surface visibility. It is one of the most dangerous hazards to aviation. Some progress has been made in the development of aids to overcome its danger but none have as yet been perfected.

Ordinarily fog is formed when moist air is cooled until the dew-point temperature is reached. Any further cooling will then cause

condensation to take place. However, the addition of moisture to the air will cause the dewpoint to rise and so approach the air temperature. A combination of rising dewpoint and falling temperature will thus cause fog to form also.

Fogs are ordinarily placed in two general classes, depending on which of these two effects is predominant. These are *air mass fogs* and *frontal fogs*. In the first, falling temperature is the controlling

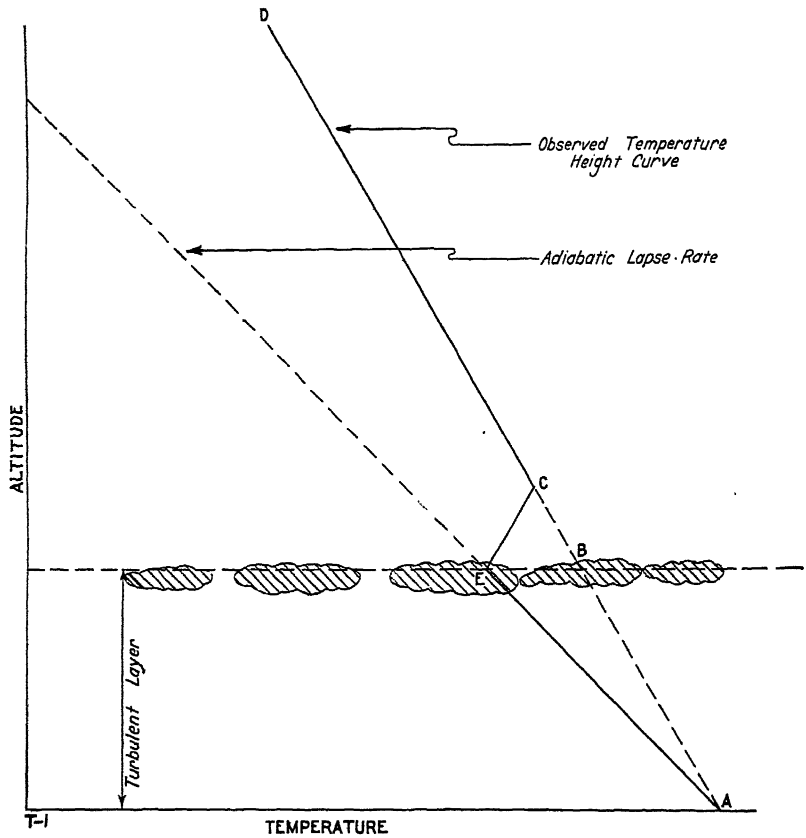

FIGURE 113.

factor, in the second the rising dewpoint due to increased moisture from precipitation is usually more important. The two main classes are further subdivided into several types but space will not permit more than a description of the more important ones.

Under air mass fogs we find advection and radiation types. Advection-type fogs depend on the horizontal transport of air between regions of contrasting surface temperatures. This usually means the moving of warm moist air over colder surfaces, but in Arctic regions the reverse occurs giving rise to *steam fogs* or *arctic sea smoke*. The

usual type occurs when warm moist air from the water moves in over the colder land and is cooled to the condensation point, or when air from a warm ocean current moves over a colder one and is then cooled. Radiation types occur when the moist air is cooled by the loss of heat from the surface over which it lies. This ordinarily occurs on clear nights with little wind movement. After nightfall the ground loses its heat and the layers in contact with it are cooled. The light wind carries this cooled air aloft a short distance. As the process is repeated, the ground continuing to lose its heat, the lower layers are cooled more and more and if sufficient moisture is present fog will soon form. Ground fog is the common name for radiation fog. It is usually quite shallow and is quickly dissipated by the heat of the day.

These fogs require light to gentle winds for their formation. With stronger winds there is considerable surface turbulence and the cooling is carried farther aloft, resulting in the formation of a stratus cloud at the top of the turbulent level as pointed out previously.

Frontal fogs are formed by the saturation of the air by the falling precipitation. This causes the dewpoint to rise until it coincides with the air temperature. Frontal fogs may be: *prefrontal* (warm front type), *post frontal* (cold front type) or *front passage* fogs. Of these the prefrontal type will likely be of greater extent. Here again the wind velocity is important. Ordinarily the winds in advance of the front are too strong to permit fog formation, so low stratus clouds are more common. However, a good cold air mass with a stable lapse rate in advance of a warm front when the winds are light is a favorable place for such fog formation. When the precipitation band is wide and the winds are light over a wide distance the prefrontal fog may be quite extensive. Post frontal fog is formed the same way as prefrontal fog, but as the precipitation band is seldom very wide the fog is less widespread. Front passage fogs may be formed in a number of ways. The rapid advance of cold air over warm moist ground at the time of a well marked passage can produce it. It can also be formed for a short time as the front passes by the mixing of the cold and warm air masses in the frontal zone if both air masses are near saturation and the winds are very light.

THE WEATHER MAP

In North America, some several hundred stations are maintained by the United States, Canadian, and Mexican Weather Bureaus for periodically observing the weather conditions. These stations observe and report the following information to a central office at certain specified times.

1. State of weather.

2. Force and direction of wind.
3. Current temperature.
4. Maximum or minimum temperature.
5. Barometric pressure corrected to sea level.
6. Amount and character of barometric change for previous three hours.
7. Dewpoint and temperature.
8. Past weather, including character, amount and time of beginning or ending of precipitation.
9. Clouds, type, amount, and direction of movement.
10. Ceiling and visibility.
11. Winds aloft and aerograph soundings are sent in by certain selected stations which have the facilities to obtain this information.

In addition to the regular reporting stations, certain selected ships which travel the established routes in the Atlantic, the Gulf of Mexico, and the Pacific, observe and report much of the above information.

Reports are sent in at 0200, 0800, 1400, and 2000 eastern standard time. This permits the drawing of four maps daily. All stations do not report every time, some of the small ones reporting only at 0800, others only at 0800 and 2000.

As the reports from the regular reporting stations and ships come into the Weather Bureau, they are broadcast by the naval communication system. Complete information regarding the time and nature of these broadcasts is contained in "Radio Aids to Navigation" published by the Hydrographic Office.

AIRWAY WEATHER SERVICE

A successful solution of the weather problem for aviation requires, first of all, a dense network of surface and upper-air observation stations, manned by trained observers, and the rapid transmission of frequent reports from these. Secondly, it requires a technical staff of employees at terminal airports to prepare frequent weather maps, upper-air charts, and diagrams from which a picture of the changing weather situations may be presented; and, thirdly, it requires competent meteorologists to analyze the current weather conditions, anticipate the development of new situations, compute the movement of pressure systems, and to issue, on the basis of these, short-period forecasts for the route to be flown. In constantly endeavoring to maintain as complete a service as possible the Weather Bureau has established several hundred stations at fairly regular distances apart along the civil airways in the United States, Alaska, and Hawaii, and, in addition, a large number of stations rather uniformly distributed off the airways for reporting weather. Reports are collected by teletype and radio from airway stations and by telegraph and telephone from

off-airway stations, and are relayed to required points along the airways by the Civil Aeronautics Authority radio and teletype systems. There are well-distributed stations, equipped for taking upper-air wind observations, and additional stations at which upper-air observations are made by airplanes and by instruments which are carried aloft by balloons and report conditions through the medium of radio signals (radiosonde). At important airway terminals, qualified meteorologists of the Weather Bureau are on duty 24 hours a day charting and analyzing weather reports and discussing the meteorological conditions with pilots.

Weather observations are taken hourly throughout the 24 hours at most of the stations located on civil airways. Special observations are taken at these stations whenever marked changes in weather conditions occur. At stations located off the airways, observations are taken every 6 hours, and every 3 hours at a few designated to do this. Reports from ships at sea, made twice daily, are also available. Observations generally consist of ceiling (height of cloud layer above the ground) in feet; sky conditions; visibility in miles; weather conditions (including precipitation, squalls, etc.); obstruction to vision (fog, haze, etc.); temperature; dew point; wind direction and velocity; barometric pressure; pressure change tendency; amount, type, and direction of clouds, and miscellaneous information (thunderstorms, line-squalls, etc.). To facilitate the transmission of the reports, they are put into a symbol, word, or figure code, depending upon the type of observation and whether the station making the report is on an airway, is an "off-airway" station, or a ship at sea.

A system of teletype and radio circuits is provided by the Civil Aeronautics Authority for the rapid collection and distribution of weather information. Such a communication system is essential for an effective airway weather service. The weather observations are collected in sequences each hour, beginning with the first station on each circuit and continuing station after station, in their proper order along the airway, until all reports of that circuit are collected. The reports of each circuit are then automatically relayed to such other circuits as require them. Complete weather information is thus made available at every important airway terminal as soon as the sequence collections and relays have been completed, which is only a few minutes after the meteorological observations represented by the report have been made. The reports are broadcast by radio to pilots in the air, posted on Weather Bureau bulletin boards, entered on meteorological charts and maps, and disseminated by telephone and interphone systems as they are received, so that pilots and air-line dispatchers have a constant knowledge of the latest developments in meteorological conditions.

Stations off the airways report by telephone and telegraph and these reports are collected at designated centers and relayed to teletype circuits for distribution to all stations where required.

The data contained in the weather broadcasts and on airway reports are entered on blank maps and weather maps are constructed from these data. A description of the method of entry of data and construction of weather maps is of such length that it cannot be included in this manual, but complete instructions in the methods used by the U. S. Army, U. S. Navy, and the U. S. Weather Bureau are set forth in Chapter II, Aerographers' Manual, issued by the Bureau of Aeronautics, Navy Department, Washington, D. C.

CHAPTER VIII

NOMENCLATURE OF AIR NAVIGATION

(ABBREVIATED)

For additional terms refer to Nomenclature for Aeronautics, published by National Advisory Committee for Aeronautics

Aircraft navigation computer.—A device for computing speed, time, distance, true air speed, ground speed, and true altitude.

Aircraft plotter.—A device for plotting tracks, headings, bearings, and position lines on a chart. A protractor is usually incorporated.

Air navigation.—The art of determining the observer's geographic position, and maintaining the desired motion of an aircraft relative to the earth's surface by means of pilotage, dead reckoning, celestial observations, or radio aids.

Air speed (*A. S.*).—The speed of an aircraft relative to the air. It is the true air speed unless otherwise stated.

Air temperature.—Temperature of the air at the altitude being maintained by an aircraft.

Altimeter.—An instrument that indicates the elevation of an aircraft above a given datum plane. A barometric altimeter does this by measuring the weight of air above it. A radio altimeter, usually referred to as an absolute altimeter utilizes the time interval between a radio signal and its echo returned from the ground.

Altitude of Aircraft (*Alt.*).—Corrected altitude is the true height above sea level. The corresponding pressure altitude is the true altitude less the correction for temperature and existing barometer reading, and is the corresponding indicated altitude when the correction scale is set to zero or 29.92 inches of mercury. The corresponding indicated altitude is the altitude reading after the altimeter has been set to read 0 at sea level. Absolute altitude is the true height above the ground.

Artificial horizon.—An instrument indicating the attitude of an aircraft by simulating the appearance of the natural horizon with reference to a miniature airplane.

Automatic pilot.—An automatic mechanical device capable of controlling the motion of an aircraft.

Azimuth (*Zn.*).—The true bearing of a celestial body.

Bearing (*Brg.*).—The direction of one object from another, expressed as an angle measured clockwise from true north.

Bubble octant.—An astronomical instrument generally used to measure the vertical angle of celestial bodies from the instrument's bubble horizon or at times from the natural sea horizon.

Celestial navigation.—The method of determining the observer's geographic position by sextant or octant observations of celestial bodies.

Chart.—A flat surface showing latitude and longitude lines, compass roses, and representations of ground objects, with various aids to navigation.

Compass (Comp.).—An instrument indicating the angle between the longitudinal axis of the aircraft and the axis of the compass needle. A magnetic compass unless otherwise designated.

Compass calibration.—The process of determining the deviation of a compass with respect to magnetic bearings on various headings of the aircraft.

Compass compensation.—A practical method of applying magnets or other correctors to neutralize the magnetic forces exerted on the compass by the aircraft structure and equipment.

Compass rose.—A circle, graduated in degrees from 0° to 360°, placed on maps, charts, plotters, plotting boards and protractors, as a means of ascertaining direction. A graduated circle, marked on the ground to accommodate the compensation of an aircraft's magnetic compass.

Course.—(C) The true direction over the surface of the earth that an aircraft or ship is intended to travel.

Dead reckoning (D. R.).—The method of estimating the actual or intended position of an aircraft or ship. The D. R. position is indicated by ⊙, with a notation of the time.

Departure, Point of (Dep).—A specified position at some particular time of commencing a course or track of an aircraft or ship to some destination.

Deviation.—The angular difference between the magnetic heading and compass heading of an aircraft, due to magnetic attraction in the vicinity of the compass.

Distance (Dist.).—The number of miles between any two points, usually expressed in nautical miles. A nautical mile is 6,080 feet. A statute or land mile is 5,280 feet.

Double drift.—A method of determining the force and direction of the wind by observing the drift angle on each of two headings at a known air speed.

Drift angle.—The horizontal angle between the longitudinal axis of an aircraft and its path relative to the ground.

Drift sight.—A device used to determine the drift angle by observation; or the process of taking an observation with such a device.

Estimated time of arrival (E. T. A.).—The predicted time that an aircraft will reach its destination or turning point.

Fix.—The intersection of two or more simultaneous lines of position or bearings.

Float light.—A device emitting smoke and light when dropped on the water to furnish a reference point on the surface for maintaining a position or taking a drift sight.

Geographic plot.—A diagram indicating successive D. R. positions or fixes of an aircraft or ship.

Great circle.—A circle on the earth's surface whose plane passes through the center of the earth.

Great circle course.—The shortest route between any two places along a great circle running through both places.

Ground speed.—The predicted or observed speed of an aircraft over the surface of the earth.

Ground speed meter.—A device for determining the speed of an aircraft along its track.

Heading.—The direction with respect to true north in which the longitudinal axis of an aircraft is pointed or heading. The corresponding magnetic heading is the true heading with the variation applied. The corresponding compass heading is the magnetic heading with the deviation applied.

Homing.—The process of flying toward a transmitting station by means of the loop antenna or radio direction finder.

Homing loop.—An antenna having directional qualities with regard to a received radio signal.

Knot (kt.).—The unit of speed used in navigation and representing one nautical mile per hour. It is equal to 1.15 statute miles per hour.

Latitude (Lat.).—The angular distance of any point on the earth's surface north or south of the equator.

Line of position.—A straight line tangent to a circle of equal altitude on which the ship is located somewhere in the vicinity of the D. R. position.

Log.—A written record of computed or observed navigational data.

Longitude (Long.).—The angular distance east or west between the Greenwich, prime meridian, and the local meridian of any point on the earth's surface.

Lubber's line.—A prominent fixed line on the aircraft compass, drift sight, directional gyro, pelorus, and radio direction finder loop, oriented parallel with the aircraft's longitudinal axis to furnish a reference point to indicate a heading or bearing.

Mercator radio correction.—The correction that must be applied to a true radio bearing before it can be plotted as a straight line on the Mercator chart.

Mercator course.—A straight course or track line on the Mercator projection that intersects every meridian at the same angle.

Northerly turning error.—The change of compass reading when the axis of the magnetic element is displaced East or West of the vertical.

No-wind position.—The position in which an aircraft would be at a given time if there were no wind.

Pelorus.—A device by which the bearing of a sighted object may be determined.

Pilotage.—The method of conducting an aircraft from one point to another by observation of landmarks.

Plotting sheet.—A plane surface sheet provided with latitude and longitude lines, or the means for plotting them, together with a compass rose, but without other representation of land objects.

Protractor.—A device graduated in degrees, used in orienting lines on some form of plotting surface.

Radio bearing.—A true bearing obtained by a radio direction finder station.

Radio direction finder (R. D. F.).—A device for indicating the direction of a transmitting station.

Radio navigation.—The method of conducting an aircraft from one point to another by radio aids to navigation.

Radius of action.—The distance that an aircraft can fly in a given direction before returning to a base in a given length of time determined by fuel capacity, daylight, or other considerations.

Rate-of-climb indicator.—An instrument indicating rate of ascent or descent of an aircraft.

Relative bearing.—The direction of an object expressed as an angle measured clockwise from the heading of an aircraft or from the bow of a ship.

Relative motion.—Motion of an aircraft relative to a moving ship. Direction of relative motion is the direction of a line representing such motion. Speed of relative motion is the rate of motion along a line representing the direction of relative motion. Miles of relative motion is the distance traveled by an aircraft along a line representing the direction of relative motion.

Rhumb line.—The same as the Mercator course.

Running fix.—The intersection of two or more non-simultaneous lines of position or bearings run up to a common time.

Sector of reliable calibration.—The sector in which radio bearings taken by a land station are not distorted by intervening terrestial objects.

Sextant.—A navigational instrument used to measure the vertical angle of celestial bodies from the natural horizon, or to measure the horizontal angle between terrestial objects.

Sight.—The process of observing a celestial body to determine its vertical angle above the horizon.

Swinging ship.—Compensation and calibration of a compass obtained by swinging the aircraft on different compass headings.

Track.—The true course or direction between stations on the surface of the earth that an aircraft has traveled.

Turn and bank indicator.—An instrument for indicating the rate of turn of an aircraft and whether or not it is banked properly.

Variation (Var.).—The angle between the true meridian and the magnetic meridian, expressed in degrees and minutes east or west of the true meridian.

Wind correction angle.—The angle between the heading and the course of an aircraft.

Wind direction and force.—The direction from which the wind blows and the speed at which it blows.

Wind star.—A solution for the direction and force of the wind by the double-drift method.

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